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GENERAL AND PROFESSIONAL BIOLOGY

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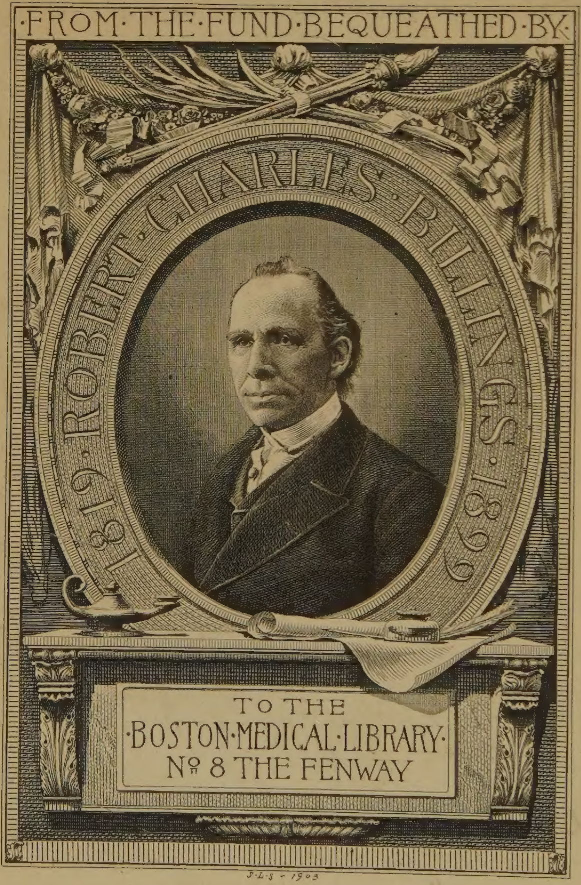
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General and Professional Biology

GENERAL AND PROFESSIONAL
BIOLOGY

with Special Reference to Man

(A One or Two-Year Course, Including Introductory Embryology and Comparative Anatomy)

BY

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To My Students

whose loyalty and appreciation have been my
inspiration throughout the years this
book has been in preparation.

PREFACE.

Teachers of the Biological Sciences have often observed that:

(1) The majority of American College Students are the children of parents who have not had a college training and, therefore, have no proper conception of what a college course means nor an understanding of the reasons that lead educators to choose certain particular studies for the curriculum instead of others.

(2) The work done by the average student up to his entry into College has neither taught him HOW to study, nor how to coördinate the work of the various courses he has had.

(3) The technical words he has met with have not been analyzed, so that he has no conception of their derivation, and, consequently, of their true meaning. He has largely memorized whatever was learned with little understanding of meanings.

(4) The professional world (especially of Medicine and Dentistry) is in general accord with the idea that "General Biology" or "General Zoölogy" should be followed by "Introductory Embryology" and "Comparative Anatomy."

(5) Most texts on the Biological Sciences either try to make the subject matter entirely too easy, and thus forget to mention the many points of prime interest to professional students, or they try to cover the entire range of animal biology, thus burdening both book and student with matter that is going to be forgotten as soon as examinations are passed.

(6) The student is, therefore, confronted with several alternatives: either he takes the "easy" course and feels that because he was told so little, there is but little to be told, or, if the more detailed course has been taken, he finds that it has helped but little, if any, to assist him in his chosen field, and he is rightfully disappointed.

(7) The terminology in Botany, Zoölogy, and Medicine is by no means identical, and much must be re-learned by professional students.

(8) A textbook usually confines itself to "Type Forms" or to "General Principles." In either case the student suffers for want of the half that is left untold.

(9) Results of scientific work are often given, such as the life-cycle of the Malarial Parasite, without showing in detail the type of work necessary to bring about those results, thus preventing the student from gaining one of the most valuable lessons of his scientific course.

(10) Medical and Dental educators, as well as students themselves, are constantly complaining of the insufficient stress placed on Histology

and Neurology in the preliminary courses, as it is in these fields that so many students later find their greatest difficulties.

(11) Medical educators insist that in a few years all medical schools must add a course in Medical Zoölogy. The students who are now being prepared for these courses must obtain an adequate number of examples of animal parasites in their pre-medical studies or they will not be able to profit fully when such later course is taken.

(12) The student now purchases three, and often four, texts for his biological work, none of which is a true continuation of its predecessor.

(13) When studying a given biological problem, constant reference must be made to facts and findings of various kinds for the purpose of checking up and coördinating the work one is doing. If a student must seek through many volumes for such references he is all too apt not to look for any at all, whereas if he has but to turn a few pages, he will almost invariably search out many.

Being confronted with points such as these, and wishing to obtain the professional student's point of view as well as an understanding of his difficulties, the author took the regular laboratory courses offered in American Schools of Medicine and has built this book on what experience taught him to hold most valuable.

Therefore, he begins (1) by showing the student WHY to study, and (2) HOW to study and HOW to COORDINATE the various courses of the curriculum. (3) The glossary is made quite complete by giving both derivations and pronunciations of all technical words used in the text and the student is then obliged to write them out in the parentheses left blank for that purpose. (4) "General Biology" is followed by "Introductory Embryology" of the Chick and Frog, together with a general statement regarding Mammalian Forms, thus presenting to the student the beginnings of a Comparative Study. This, then, is followed by "Comparative Anatomy" where constant comparisons are not only made, but where back references are always being brought into play, so as to force a repetition, so essential to a full understanding of all scientific work.

(5) One subject (The Frog) is treated exhaustively so that the student will not be burdened with too good an opinion of his own knowledge of even so humble a thing as the frog, while principles are always presented AFTER the facts have been shown upon which those principles rest.

(6) The entire work is concentrated and by no means "easy." The goal of the student is kept in mind.

(7) The terminology that the professional student is going to use later is always borne in mind and stressed.

(8) "Type Forms" are studied, but only in so far as these are necessary to a full and complete understanding of both the anatomy and

physiology of the animal and to furnish the facts on which to build interpretations and principles.

(9) In such work as that on the Malarial Parasite the result of scientific work is first shown so as to cause the student to wonder how such a mass of intricate detail could ever have been discovered. Then a detailed account of the painstaking and intelligent effort necessary to make such findings valuable is given.

(10) Histology and Genetics are stressed because in all biological work a thorough knowledge of the cell and tissues is a prerequisite for further work, and Neurology, because of its tremendous importance in all Biological, Psychological, and Medical fields.

(11) Examples, wherever possible, have been chosen in so far as they add to, or detract from human welfare, for, after all, Students of Education, Law, Philosophy, Psychology, Sociology, Theology, Economics, Engineering, Medicine, and Dentistry are, and must be, most interested in Man.

(12) All that is needed for two complete years of biological work is contained within this one volume, each part logically following the part preceding, thus not only saving the student considerable time and expense, but also serving him as a sort of continual reference work in his future professional years of study. Both the Bee and the Grasshopper have been included so that teachers may use their preferred form.

(13) Then, too, the student, having his entire course of work before him in a single volume, often, of his own volition, reads much more than he normally would were the subject matter scattered through several texts, for it is an easy matter to refer to another closely related subject if the reference can be found by a mere turning of a few pages, rather than consulting a number of separate books.

The book is so written that it can be used as a text for General Biology, General Zoölogy (by merely omitting Chapters XV and XVI) for Introductory Embryology, and for Comparative Anatomy.

Where only one year is given to biological work, such as in many Dental Schools, it is suggested that the first semester be given to "General Biology" or "General Zoölogy" made up of selected chapters from the first half of the Text, while the second semester be confined to the higher forms such as Dogfish, Turtle, and Cat or Rabbit, as found in "Comparative Anatomy."

The Laboratory Manual to accompany "General Biology" and "Introductory Embryology," written by Professor John Giesen, will be ready for general distribution by June, 1923.

Dr. L. H. Hyman's "A Laboratory Manual for Comparative Vertebrate Anatomy" (University of Chicago Press), is being used for the Comparative Work in Anatomy.

Long Bibliographies have not been given in this book, as these are seldom consulted by a student during the first two years of his college career. However, as all of the books mentioned below should be in every College Library, those who wish such bibliographies can find the best of them in Kellicott's "Chordate Development," Patten's "The Early Embryology of the Chick," and Kingsley's "Comparative Anatomy of Vertebrates."

It is much more important for the student to know **HOW to Compile a Bibliography** than to look over one already made. Therefore at Marquette University a different subject is assigned each student to look up for the purpose of compiling a bibliography of everything written on that subject for the past forty years. Such subject may be taken from any Index of the Journal of the American Medical Association.

Forty years are chosen because it is about that many years ago that some of the larger indices were compiled, and it is essential that the student be forced to go through all the indices year by year. If the indices are not found in the smaller towns and cities, the bibliography can be made during one of the vacations when the student passes through some of the larger cities where there is a Medical or Scientific Library.

The more important Indices published in the English Language are:

The Zoological Record (published yearly by the Zoological Society of London. Each volume gives a complete list of the works and publications relating to zoology in all its branches that have appeared during the preceding year. The first volume was for the year 1864).

The Index Medicus (Found in any Medical Library).

Index Catalogue of the Surgeon General's Office.

International Catalogue of Scientific Literature, "Zoology," "Botany," "General Biology." (Pub. by Harrison & Sons, 45 St. Martin's Lane, London.)

For Popular Articles:

The Reader's Guide to Periodical Literature.

The International Index to Periodicals. (Before Jan., 1921, The Reader's Guide to Periodical Literature Supplement.)

The books which have been of greatest service to the author are:

On General Biology

Parker and Haswell, "Text-book of Zoology."
L. A. Borradaile, "A Manual of Elementary Zoology."
Shipley and MacBride, "Zoology."
R. W. Hegner, "College Zoology."
J. G. Needham, "General Biology."
Linville and Kelly, "A Text-book in General Zoology."
O. H. Latter, "The Natural History of Some Common Animals."
Schull, Larue, and Ruthven, "Principles of Animal Biology."
A. M. Marshall, "The Frog."
S. J. Holmes, "The Biology of the Frog."
H. S. Pratt, "A Manual of the Common Invertebrate Animals."
Ward and Whipple, "Fresh-Water Biology."
Sanderson and Jackson, "Elementary Entomology."
Leland O. Howard, "The Insect Book."
J. H. and Anna B. Comstock, "A Manual of the Study of Insects."

Frank E. Lutz, "Fieldbook of Insects."
J. W. Folsom, "Entomology with special reference to its Biological and Economic Aspects."
Riley and Johannsen, "Handbook of Medical Entomology."
W. T. Calman, "The Life of Crustacea."
R. W. Hegner, "The Germ-Cell Cycle in Animals."
W. E. Agar, "Cytology, with Special Reference to the Metazoan Nucleus."
L. Doncaster, "An Introduction to the Study of Cytology."
L. W. Sharp, "Introduction to Cytology."
C. Hill, "A Manual of Normal Histology and Organography."
Krause-Schmahl, "A Course in Normal Histology."
W. E. Castle, "Genetics and Eugenics."
E. G. Conkin, "Heredity and Environment in the Development of Man."
C. B. Davenport, "Heredity in Relation to Eugenics."
East and Jones, "Inbreeding and Outbreeding."
H. E. Walter, "Genetics."
T. H. Morgan, "A Critique of the Theory of Evolution."
S. J. Holmes, "The Evolution of Animal Intelligence."
M. F. Washburn, "The Animal Mind."
H. S. Jennings, "Behavior of the Lower Organisms."
Eric Wasmann, "Instinct and Intelligence in the Animal Kingdom."
James Johnstone, "The Philosophy of Biology."
A. D. Darbishire, "An Introduction to a Biology and Other Papers."
Vernon L. Kellogg, "Darwinism Today."
Wm. A. Locy, "Biology and Its Makers."
H. F. Osborn, "From the Greeks to Darwin."
C. E. and E. A. Bessey, "Essentials of College Botany."
Bergen and Davis, "Principles of Botany."
C. S. Gager, "Fundamentals of Botany."
Wm. C. Stevens, "Plant Anatomy."
Strasburgher's "Textbook of Botany."
D. H. Campbell, "A University Textbook of Botany."
Coulter, Barnes, and Cowles, "Textbook of Botany."
I. F. and W. D. Henderson, "A Dictionary of Scientific Terms."

On Embryology

F. R. Lillie, "The Development of the Chick."
W. E. Kellicott, "Chordate Development."
B. M. Patten, "The Early Embryology of the Chick."
Prentiss and Arey, "Textbook of Embryology."

On Comparative Anatomy

G. C. Bourne, "An Introduction to the Study of Comparative Anatomy."
J. S. Kingsley, "Comparative Anatomy of Vertebrates."
L. Vialleton, "Elements de Morphologie des Vertebres."
Schimkewitch, "Lehrbuch d. vergl. Anatomie d. Wirbelthiere."
H. H. Newman, "Vertebrate Zoology."
H. W. Wilder, "History of the Human Body."
Parker and Haswell, "A Textbook of Zoology."
L. H. Hyman, "A Laboratory Manual for Comparative Vertebrate Anatomy."
H. S. Pratt, "A Course in Vertebrate Zoology."
Reighard and Jennings, "Anatomy of the Cat."
Davison and Stromsten, "Mammalian Anatomy, with special reference to the Cat."
O. C. Bradley, "A Guide to the Dissection of the Dog."
Hans Gadow, "Amphibia and Reptiles."

B. F. Kaupp, "The Anatomy of the Domestic Fowl."
C. J. Herrick, "An Introduction to Neurology."
Emil Villiger, "Brain and Spinal Cord."
S. W. Ransom, "The Anatomy of the Nervous System."

The author wishes at this point to thank all those who have assisted him in any way.

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Thanks are due the publishers, not only for their excellent work, but for their constant willingness to render every assistance possible to lighten the work of the author.

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And lastly, the author would be remiss in his duty did he not express his special thanks and appreciation to his co-worker of many years, Professor John Giesen, whose loyalty and willingness to assist in every way have made many additional hours of work possible on this book.

EDWARD J. MENGE.

Marquette University,
Milwaukee, Wisconsin,
June 25, 1922.

CONTENTS

Chapter Page

Part I—General Biology 19-432

I. Why To Study 19
II. How To Study 27
III. The Co-ordination of Subjects Studied 34
IV. The Frog 43
V. The Cell 88
VI. The Chemistry of Living Matter and Cell Division 94
VII. Histology of the Frog 108
VIII. Summary of the Frog 117
IX. The Protozoa 121
X. Interpretation of the Facts thus far presented 157
XI. Genetics 165
XII. Animal Psychology 172
XIII. Intermediate Organisms 185
XIV. Immunity 194
XV. The Plant World 202
XVI. The Plant World Continued 215
XVII. The Coelenterata 247
XVIII. Introduction to the Coelomata 258
XIX. The Earthworm 262
XX. Flatworms (Platyhelminthes) and Threadworms (Nemathelminthes) 285
XXI. The Arthropoda 312
XXII. Insects at Large 328
XXIII. The Grasshopper 332
XXIV. The Honey Bee 353
XXV. The History of Biology 375
XXVI. Paleontology 393
XXVII. Evolution 402
XXVIII. Classification 414

Part II—Introductory Embryology 433-663

(Chick, Frog, Mammal)

EMBRYOLOGY OF THE CHICK 435-542

XXIX. The Development of the Embryo before the Egg is laid 435
XXX. The Primitive Streak and Origin of the Mesoderm 455
XXXI. The Four to Six Somite Stage (About 24 Hours) 465
XXXII. The First Half of the Second Day (24-36 Hours) 470
XXXIII. The Second Half of the Second Day (36-48 Hours) 476
XXXIV. Extra-Embryonic Membranes 485
XXXV. Development of the Third Day 489

Chapter Page

XXXVI. The Differentiation of the Somites 502
XXXVII. The Development of the Fourth Day 508
XXXVIII. The Coelom and the Mesenteries 536
XXXIX. Development of the Fifth Day 538

EMBRYOLOGY OF THE FROG 543-618

XL. The General Embryology of the Tadpole as compared with that of the Chick 543
XLI. The Digestive Tract 585
XLII. The Mesodermal Somites 591
XLIII. The Circulatory System 594
XLIV. The Urogenital System 605
XLV. The Skeletal System 612

MAMMALIAN EMBRYOLOGY 619-633

XLVI. Mammalian Embryology 619

Part III—Comparative Anatomy 634-886

XLVII. Introduction to Comparative Anatomy 637
XLVIII. Classification of Fishes, Amphibians, and Mammals 639
XLIX. The Integument 664
L. The Endoskeleton 681
LI. The Digestive System 722
LII. The Respiratory System 757
LIII. The Circulatory System 772
LIV. The Urogenital System 806
LV. The Muscular System 826
LVI. The Nervous System 833

PRONOUNCING INDEX-GLOSSARY 887

Part I
General Biology

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CHAPTER I.

WHY TO STUDY

Two hundred and sixteen (216) **separate and distinct combinations** can be formed **by three dice of different design,** as shown by the drawing (Fig. 1).

On the principal of chance, if these three dice are thrown an infinite number of times, each one of the 216 combinations will appear just as often as every other one.

This is true only if the dice are not weighted. Combinations being formed by three dice have been chosen because there are usually at least three alternatives in any case where a man's judgment or opinion is required or asked for. Further, an analogy can be found in the complete human individual where the

Physical
Mental and
Moral

must ever be considered; while on the strictly scientific basis, everything that a man is, or can be, depends upon the three factors:

Inheritance
Environment and
Training.

Or, again, no opinion worth anything can be formed without the following three factors being taken into consideration:

Obtaining the facts
Reasoning thereon
Forming a judgment or conclusion.

Each dice possessing six sides may be compared to the many facts, conditions, or possibilities that go to make up any one of the three great factors appearing in the tables above.

It is self-evident from this that in any given case where there are three factors with six possibilities contingent upon each, **unless life's dice are weighted by knowledge, a man's opinion stands only one chance in 216 of being correct.**

The almost ideal laboratory evidence that substantiates these statements is found in the fact that out of three thousand cases at one of our leading hospitals, it has been found the diagnosticians were correct only 53.5% of the time.* **If, at our most important institutions, the ablest and best trained men, working with the finest equipment obtainable, are correct only approximately one-half the time,** it means that on the principle of chance, when anyone passes an opinion

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*"Diagnostic Pitfalls Identified During a Study of Three Thousand Autopsies," by Richard C. Cabot, M.D. *Journal of the American Medical Association*, pp. 2295-2298, Dec. 28, 1912.

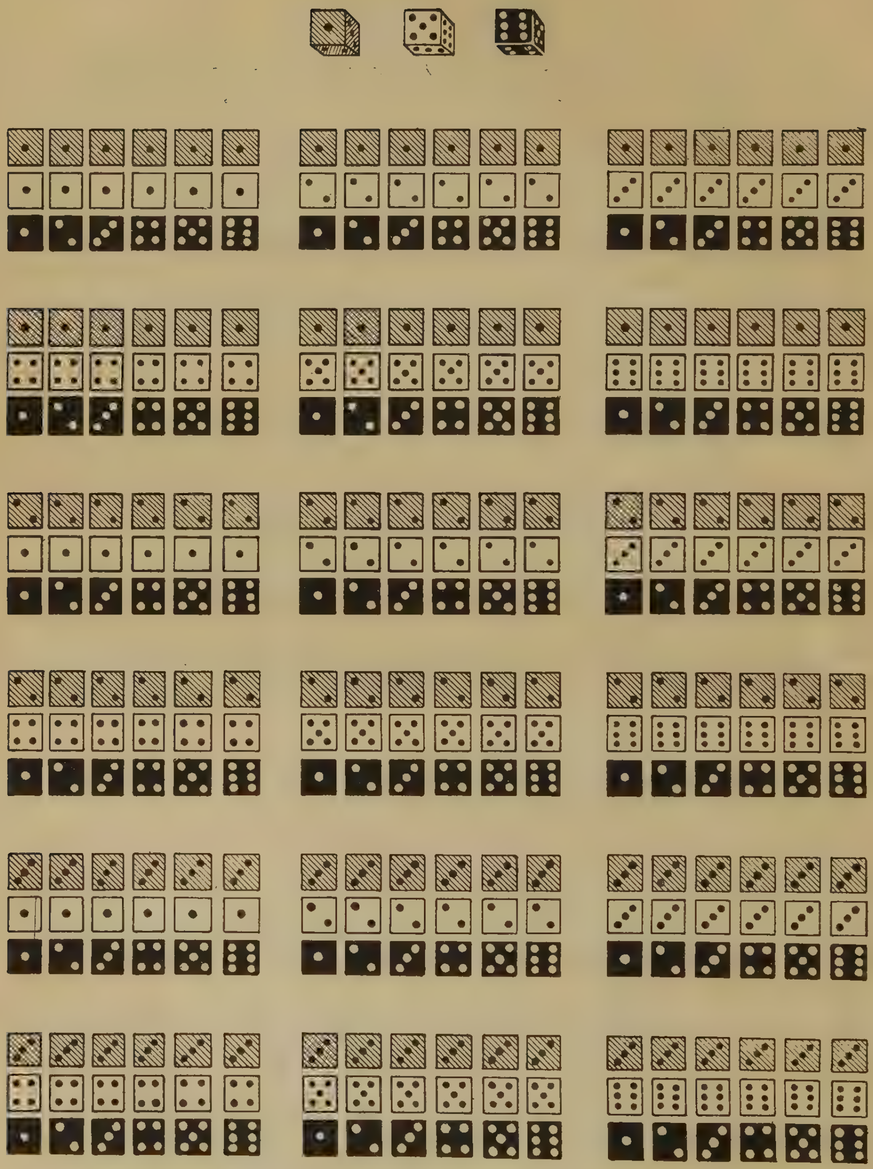

Fig. 1.

Probability of Error Chart (showing there are 216 different combinations possible with three dice of different design).

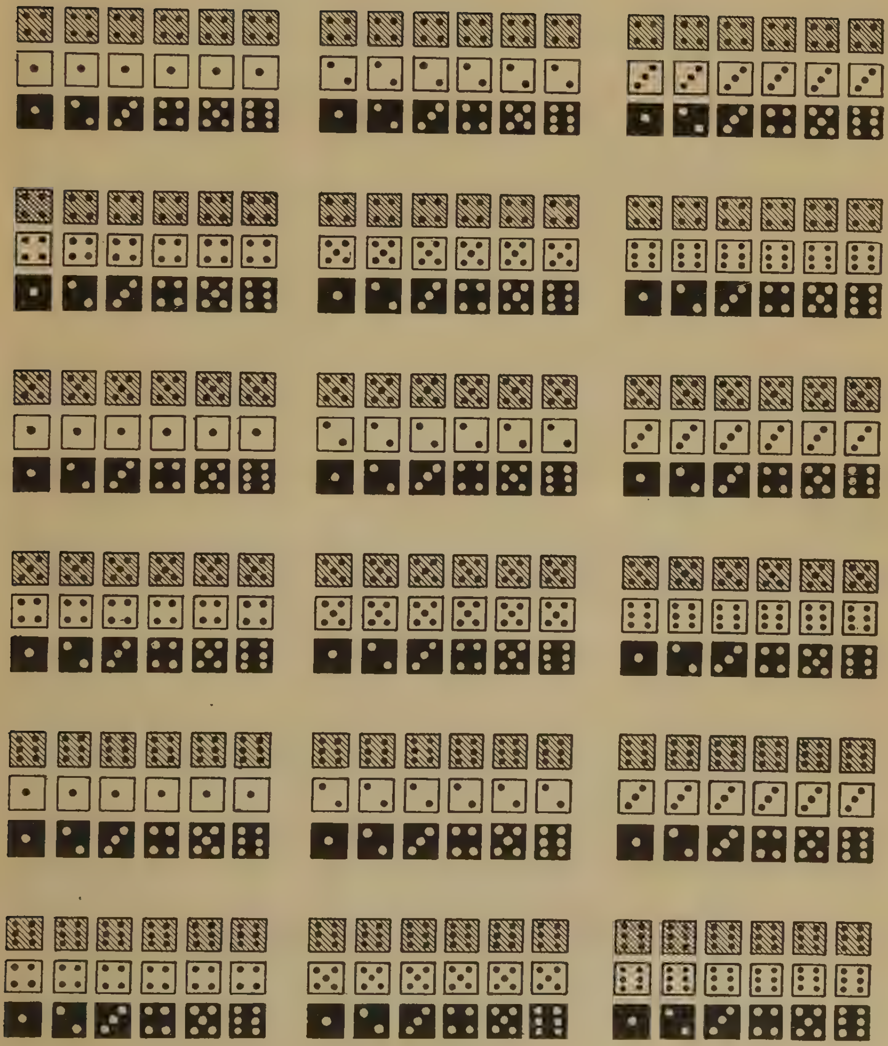

Fig. 1.

or comes **to a conclusion without all obtainable knowledge, he cannot approach correctness even this often.**

The evidence forces the conclusion that, under present conditions, if we should know all that is possible for a human being to know, we could be right only about one-half the time. As knowledge is the only way in which we can be right even as frequently as this, it follows that in instances where an opinion is called forth **without any knowledge, a man forms approximately 215 erroneous conclusions to every one that is correct.** The scriptural command becomes intelligible: "Get ye therefore knowledge."

It has been said that the evidence from diagnostic sources is almost ideal to illustrate the point here made. Everything we do that requires an opinion is pure diagnosis. In other words, every time one passes a judgment upon the facts presented, it is diagnosis of some kind, and any error in our diagnosis means that no intelligent suggestion can come forth as to a remedy, except on the basis of one correct one to 215 erroneous ones. The diagnosis must be correct or the remedy is absurd with the only possible exception of a guess accidentally correct.

No intelligent person wishes to have his government run, his estate adjusted, his house built, or his farm managed upon pure guess work in which the chances are two hundred and fifteen times more wrong things being done than right ones. And this is not only the case in medicine, dentistry, and the professions at large, but in the every-day **business world** as well. Dun and Bradstreet, who keep a record of **every individual** entering, as well as every one failing in business, tell us that 95 out of every 100 men who enter a commercial line for themselves fail at some time in their lives. This is due, not only to an ignorance of the particular line of work they may enter, but also to ignorance of business principles and methods at large.

To many persons it seems that the purely practically-trained individual is better equipped than he whose training has been theoretical, and individuals usually mentioned as examples to illustrate this point of view are always some of the **ablest practically-trained** men to be found, who are then compared with some of the **poorest theoretically-trained.** Because a boy is sent to college does not mean anything except, that, **if he has a capacity** for the work that he there takes up, he will be able to get the practical side of his study, while in addition he will learn **why he does what he does, when he does it.** Any man with great ability along a given line will naturally know more, and be able to work better along that line than any man without such capacity who has merely taken some theoretical course. **But,** if we take two men of equal intelligence and capacity, who take up, let us say, the plumber's trade, he who has mastered both the practical and the theoretical side of his work will always be superior to him who has become interested in only one **or** the other. It must be remembered that

(1) Capacity
(2) Opportunity, and
(3) Application

are essential to make a master of anyone in anything.

It takes considerable time to show the fruits of any study, and men are impatient for results.

Someone has truly said that the value of education consists in **knowing a man when you meet one**, which means, of course, that anyone knowing his subject-matter in a given case will be able to know whether anyone **claiming** to be an expert in that field speaks truthfully or not. It means that we must KNOW about a matter ourselves or we cannot intelligently choose worthy leaders. It means, we must be able to distinguish the gold from the dross, real ability from advertising, real scientific men from those who are simply well-known. It means we must be able to distinguish between the **real expert** and **him who calls himself one**, remembering that experts do not disagree very much, but those who call themselves experts do.

Whether we like it or not, we must acknowledge that every man who has ever lived and exercised any kind of leadership, good or bad, has left his impress upon our generation, for all those who have gone on before us and now sleep the eternal sleep, together with those living now, as well as those who are to come after us, really form a great intellectual democracy, from which all but the present generation are removed only in person. The past is with us in an overwhelming mass. The unborn are those for whom we now labor. All of our customs, our traditions, our ideas of conventional correctness and wrongness, and our laws were given us by men long since passed away. In other words, we are actually ruled by dead men.

The men who have long since passed away have given us their ideas and their thoughts **but**, to us those ideas and thoughts, those laws and traditions **must be interpreted** and our interpreters of these things are our **courts**. Mr. Taft has said, "I care not who makes the laws, if I can but interpret them." It is always meanings, interpretations, that are of most value. Now, we know that **our judges** (our legal interpreters), are practically **all college men**, which means that, in the final analysis, **everyone of us is controlled by what our institutions of higher learning teach.**

It therefore behooves each and everyone of us to obtain the requisite knowledge before forming an opinion as to whom we shall follow as leaders in every walk of life, whether this be in politics or in war, in civil or religious life, in law or in medicine, in farming or commercial pursuits, or we shall be wrong in nearly every thing we do.

Not possessed of knowledge, a man confuses sincerity with truth, forgetting that the most insane of men are intensely sincere, and that anyone following sincere but insane theories of life must quite naturally reap destruction; forgetting that to obtain the truth in anything, **all the facts must be known** and a **valid interpretation placed upon the facts,** and this can only be done by considering man in his entirety—in his physical, mental, and ethical aspects.

One must therefore weight life's dice with knowledge if correctness is to be formed in any walk of life.

Nearly every parent desirous of his child's welfare, wishes he could leave the child the benefit of his own experience, so that the child could profit by his parent's mistakes and not make the same ones. The value of this may be appreciated when it is remembered that if this cannot be done, there is absolutely **no progress.** For, each individual, instead of starting where his parents left off and continuing onward, would necessarily have to begin where they began, and, consequently, when life came to a close they would be exactly where their parents had been at the same time.

Men of the past have therefore written their experience in books, and we of to-day can profit not only by the experience of our immediate parents but by the experience of all our forefathers.

The laboratory has gone even a little further than this.

As no one man could work out every detail in the study of a single plant or animal without having to take the work of all those into consideration who had gone before and who had contributed something to the knowledge of the particular plant or animal under discussion, so, men have gathered into a single grouping the important physical experiences which have been found convincing to their minds and have called such grouping a **textbook.**

The study of the subject-matter of such textbook, plus the actual working out of these same convincing experiences (now called **experiments**) in the laboratory, cause the student actually to **see** the way in which **proof** is obtained for the various conclusions men hold.

In fact, laboratory work, plus a study of the text, is the fulfillment of the parent's wish that his child inherit the parent's experience.

From the experiment which thus gives us conclusive evidence of the way some **physical process works,** we draw our **principles.**

Principles are **mental tools** without which no mental progress would be possible.

In fact, a principle is a **law of nature, proved by physical experiment, to which no exception has been found.** Physics presents an excellent illustration of the value of principles.*

Everyone knows that if a substance, such as iron, which is heavier than water, is placed in water it will sink. Yet iron ships do not sink.

---

*An old Greek named Archimedes, while taking a bath, discovered that when he immersed his body in a tub filled with water, his body lost considerable weight. Later he was able to prove experimentally that the weight of the water that ran over the top of the tub was exactly the same as the weight his body lost while immersed. It was this discovery which made iron ships possible.

Why? Because what we mean by "heavier than water" is that the same quantity of a given substance is heavier than the same quantity of water.

After Archimedes discovered his **principle**, we knew immediately that if we could bend iron so that it would occupy more cubic feet of space than that same number of cubic feet of water would weigh, it would be "lighter than water" and would float.

Heavy iron ships could not, however, be of practical use until some one again discovered the principles of steam or electricity, and so they were not used until such principle was found. This shows well the inter-relationship of things that men do, no matter how many years apart the doing may be.

In Biology, which means the Science of Life, (Gr. Bios=life+logos=discourse) we are interested in finding **principles**, so that no matter in what position we may be placed in later life, we can always think back, find our principle, and apply it in a thousand and one different ways.

The finding of principles, which is real science, must never be confused with the application of these principles.

The former is what is meant by science while the latter is merely ordinary labor.

Inventors **apply scientific principles, they are therefore not scientists.**

Another point to be remembered is that animals (as well as children before they reach the so-called age of reason) **learn** by doing a thing over and over, until success or failure comes. If success comes, they make such successful endeavor a part of their later life. This is called the **trial and error** method of learning.

Educated men and women **do not try out** each and everything, but come to their conclusions by weighing the **evidence for and against a principle**, and if the principle is found to be worthy of consideration, adjust their actions accordingly.

This is well illustrated if one finds a man attempting the invention of a perpetual motion machine.

It is a well established **principle of physics** that no more work can be obtained from a machine than is put into it, and even then a little loss must be allowed for on account of friction.

All educated men know this law of nature, and consequently do not waste their time on such a fruitless undertaking.

But, should any one refuse to accept this principle, there is nothing left but to continue trying and trying, and coming to the conclusion of its uselessness by personal failure. The **obtaining** of principles is then the **great work of science**. Science itself has had many definitions. Some of the best are:

"Systematized knowledge."

"Classified common sense."

"Checking up and getting rid of one's prepossessions."

"Knowledge gained and verified by exact observation and correct thinking, especially when methodically formulated and arranged in a rational system."

In other words, science means a gathering of facts, plus the logical meanings or interpretations of these facts.

The object or purpose of getting the principles which science thus finds, is to control nature and to prophesy what will occur when given acts are performed.

As Biology is the science of life, everything that has anything whatever to do with life is really a branch of this science. For example, Biology is not a branch of medicine or dentistry, but medicine and dentistry are branches of biology which must enter into particular details of some division of it.

Biology, therefore, to the medical student, the dental student, the law student, the student of sociology or the student of education, presents a sort of bird's-eye view of every one of the fundamental processes upon which his whole detailed study must be built, so that he can the better and more understandingly read the valuable and meaningful literature of the day and discuss intelligently the very basis on which his every conclusion must rest its truth. In other words, it makes it possible for the student the better to be able to prevent those who call themselves experts, but who are not, from deceptively making people believe they are.

CHAPTER II.

HOW TO STUDY

Someone has said that to be a **cultured man or woman one must know something about everything; everything about something**; and **never wilfully or maliciously cause suffering to others.**

No better ideal of what a student of biology should try to attain has ever been written. If all biological **principles** now known are grasped by the student he can most certainly be said to come as near knowing something about everything as it is possible for him to come.

If he will learn the Frog thoroughly, he can come under the second division of importance, and if he will bear the final of the three injunctions in mind, Biology will be a humanizing and cultural as well as a scientific and laboratory study.

Never read a book, article, or paper, without fountain pen and note-book or note-paper beside you.

(Probably 95% of all you are ever going to read, you will want to forget, but the remaining 5% you **will** need, and need badly when that need comes.)

I. Notes are of no value unless they are usable. There are different types of records for different purposes, but those found most convenient by the author are as follows:

For regular lectures and for general reading: A series of ordinary bond paper cut to the size of 4x6 inches.

Many of these can be carried in the pocket constantly if a little heavier paper, or even a piece of cardboard 4x13 inches is bent in the mid-line so as to form a covering for the loose cards. A rubber band is placed about the packet.

A paste-board file for this size of card can be obtained at any stationery store, and the cards then held together by fasteners can be placed under **subject headings,** ready for access at all times.

No book or article of value should be read without its **name, subject, author,** and **edition** of the book stated. (This latter is very important, because in a year or two another edition may have all its pages differently numbered, and even additions and deletions made, so that should you quote such a volume and the one to whom you are quoting, looks it up in another edition, you will be considered not only inaccurate but absolutely untruthful.)

For **clippings**—If you own the journal or paper in which an excellent article appears, cut it out. Be sure, however, to write upon it immediately the **name** of the periodical from which you clipped it, as well as the **year, month,** and **day** it appeared.

Until you have a large accumulation take ordinary long envelopes

4½x10½ inches. Fold each clipping and place it in such envelope, writing its title on the upper left-hand corner under the subject like this—

Biology
Frogs
"Different kinds of Frogs."

If you do not own the periodical, make out a **subject-card** just as you would for a lecture, and file it under the proper subject.

For your regular laboratory work you will always have your drawing book. All notes that pertain to the laboratory will be made in that.

II. Students will find that **it is easier not to take notes** on lectures.* Many think they will remember more without notes. This is true if the notes are not looked at again; but, if they are gone over from time to time, although some of the lecture may be lost by the writing, still, much that is important will be brought back to mind that would otherwise be lost.

III. Suppose you see an animal, let us say a frog. You must observe:

(1) Its external characteristics.
(2) Its similarities to the human being.
(3) Its dissimilarities to the human being.
(4) Its normal home.
(5) Its method of life.
(6) Its relations to its surroundings.
(7) The conditions under which you came to see it.
(8) Its actions, normal and when disturbed.
(9) Its own food and whether it is food in turn for other animals.
(10) How it comes to be where it is?
(11) Whether or not it remains in the same surroundings throughout the year?

This is all studied on the living frog. Every action of a living thing comes under "physiology," which is the science of **functions**. Physiology must, therefore, be studied on the living plant or animal.

V. In the laboratory you take up the **internal** structure, as well as the **development** of the organism, which means in the case of the frog, how the animal's eggs grow into a tadpole, and this into a frog in turn.

VI. You are trying to get a **complete picture** in your mind of what is known about life and you are trying to get a **gauge** by which to know when a thing is true and when it is not; consequently, you must think of these things you study just as you would if you were trying to use your camera instead of your mind for the taking of the picture.

(1.) Clear away all that is unimportant.

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*Of course, each day, after the lecture, the student is to attempt to repeat all that was said in the lecture he has heard, and when he comes to a forgotten point he must consult his notes.

(2.) Choose a subject. In this case **biology.**

(3.) Have proper **perspective** (that is, have the **relationship** of everything about your subject, in proper form, and do not unduly stress any one point). In other words, have you taken **everything** into consideration? For example, you must see to it that some other branch of science does not have some points and conclusions which may destroy yours, for if a single exception can be found in science, it has disproved the law.

(4.) There must be sufficient light to make the subject stand forth and be seen clearly. This implies a **proper background**—a background built up in the study of science by ascertaining what has gone before, and what **causes** have produced the particular historical soil upon which the seed of men's ideas have been able to grow. In other words, you must have **all the facts** that can be found, if you would have this light throw your subject into the full glare of day. You must exclude shadows as much as possible.

(5.) You must see that your subject is in focus, which means that in any given case, it must stand forth in **bold relief.** It must not fade away in the distance and become blurred by your prejudices or desires. No vagaries of thought must be permitted. Your reasoning must be clear and definite. Your whole system must be built up **philosophically and logically.**

(6.) You must decide upon how large an opening you are to allow your lens. That is, within what narrow limits you are to discuss the subject under consideration.

(7.) You must decide upon the length of time for your exposure. In a scientific treatise this means that you must know that **sufficient time has elapsed** to make your experiments valid and positive.

(8.) If you read of the results of others you must take into consideration the temperamental makeup of the individual writing as well as of yourself and other readers who later pass judgment thereon.

> **And remember that just as a football player or a musician must keep in constant practice, or lose his proficiency, so your brain must have its DAILY EXERCISE or it will likewise lose its proficiency. Further, as the distinguishing difference between man and the lower animals consists in man having an intellect, form your own conclusions.**
>
> **Remember also, that the man who can, but does not read, has not as high an intellectual ranking as he who can not read; and he who has the capacity to think but does not, ranks lower than he who is born without such capacity.**

VII. See that your note book contains complete drawings and descriptions of each of the following subjects for every form studied:

I. ANATOMY.

1. **External Makeup.**
2. **Internal Makeup.**
    - (a) Digestive.
    - (b) Circulatory.
    - (c) Respiratory.
    - (d) Excretory.
    - (e) Nervous.
    - (f) Skeletal.
    - (g) Muscular.
    - (h) Reproductive.

II. PHYSIOLOGY

1. **Processes Pertaining to Food.**

(a) Ingestion (Taking in food).
Egestion (Throwing out of undigested food).

(b) Digestion (Fermentation of ingested substance brought about by various secretions).

(c) Absorption (Passing of digested food by osmosis through body membranes and making use of inspired oxygen).

(d) Circulation (Carrying absorbed substance to all parts of the body).

(e) Assimilation (The conversion of absorbed non-living matter into protoplasm).

(f) Growth (The increase in size due to additional protoplasm being made).

(g) Reproduction (The production of new organisms similar to the parent).

2. **Processes Pertaining to Oxygen.**

(a) Inspiration (Taking in oxygen which aerates blood as it passes through lungs).

(b) Oxidation (Burning of ingested food).

(1) Secretion (Pouring out substances to be used again).

(2) Expiration (Throwing out CO_2).

(3) Excretion (Throwing out used substances in the form of urea, uric acid, etc.)

(4) Energy (a) Applied
- Response
- Behavior.
- Locomotion.

(b) Unapplied
- Heat.
- Light.
- Electricity.

III. STIMULI

Any of the processes mentioned in this outline may be made more rapid or may be slowed even to the point of complete stoppage by mechanical, chemical, and sometimes by mental **stimuli.**

IV. CLASSIFICATION

(a) Phylum.
(b) Class.
(c) Order.
(d) Family.
(e) Genus.
(f) Species.

V. Finally, remember that your study may be interpreted from any or all of the following points of view:

Both plants and animals must always be thought of when discussing living matter, and both are studied in practically the same manner. But as no one man can study all about plants or animals, or even about everything that pertains to only one plant or animal, scientific men have divided their work into group-studies as follows:

I. **Morphology:** (Gr. morphe=form) Study of Form.

1. **Promorphology** (Gr. pro=First+morphe=Form) which treats of General Form.

2. **Anatomy** (Gr. anatemno=to cut up) The study of organisms by dissection. Usually studied on the dead individual; that is, a study of Structure.

Subdivision

(a) **Gross,** or **Macroscopic** (Gr. macro=large) that which can be seen with the naked eye.

(b) **Microscopic** (Gr. micro=small) embracing the study of the more minute structures with a microscope.

Splanchnology (Gr. splanchnos=organs)
Histology (Gr. histos=web, or tissue)
Cytology (Gr. cytos=cell)
Neurology (Gr. neuron=nerve)

3. **History of Development,** that is, a study of the different stages through which an organism passes from the moment the fertilized cell begins dividing.

Individual Evolution, Embryology (Gr. en=in+bruo=bud, **Ontogeny** (Gr. on=existing+genna=to begin), the study of the individual before birth.

Racial Evolution (Phylogeny). (Gr. phylon=tribe.) The study of the race.

4. **Teratology** (Gr. teras=wonder) the study of malformations and monstrosities in organisms.

II. **Physiology.** The Study of Functions.

1. **Physiology Proper,** (Gr. physis=nature) the functional relation of part to part and to the whole.

2. **Ecology,** (Gr. oikos=house) Relations of the individual to its whole surroundings, or the study of its environment.

3. **Pathology,** (Gr. pathos=suffering). The study of disease. This study also belongs under microscopic anatomy in that disease makes many changes in the actual structure of the cells and tissues.

III. Distribution.

In Space, (Geographical Distribution, often called **Zoögeography** in so far as it affects animals).

In Time, Paleontology, (Gr. palaios=ancient—onta=beings), also called Paleozoölogy, in so far as it affects the study of fossil remains of animals.

IV. Economic Zoölogy or Botany, the study of everything living in so far as it touches human welfare.

V. Classification, or Taxonomy (Gr. taxis=arrangement+nomos=law) The grouping of plants and animals according to likeness or relationship.

VI. Psychology, (Gr. psyche=mind or soul) The study of the mind.

VII. Sociology, (L. socius=companion), the study of animal societies and their relation of each member of the society to the other. This relationship is sometimes said to be due to the so-called Herd Instinct.

VIII. Genetics (Gr. genesis=birth) The science "which seeks to account for the resemblances and differences which are exhibited among organisms related by descent."

Individual:
- **Heredity,**
- **Environment,**
- **Education,**
  - Instruction,
  - Einübung or training.

Racial: Archeology, (Gr. archaios=ancient) The study of ancient findings to ascertain the cultural state of man at different epochs.

IX. Biometrics (Gr. bios=life+metron=measure) The statistical study of life's events or happenings so as to be able to gauge how often these same events are likely to take place in the future.

Summarizing the points that must be kept in mind we may say:

1. You must be able to distinguish between **conspicuousness** and **importance.**

2. You must be able to distinguish between **fact** and **interpretation.**

3. You must be able to distinguish between **principles** and their **application.**

4. You must be able to **discuss all sides** of a subject so as to overcome scientific bigotry and narrowness.

5. You must have a knowledge of type-forms as well as the generalized biological principles which can be drawn from such knowledge.

6. You must be able to apply all the principles you have learned to the human body.

7. You must know (not only memorize) the **meaning** of the scientific words which you are called upon to use. This will be accomplished by **writing in the derivations** of the words in the parenthesis left open for that purpose. All these can be found in the glossary at the end of the volume.

CHAPTER III.

THE CO-ORDINATION OF SUBJECTS STUDIED

Comparatively few students either grasp or understand the value of the various studies laid out for them by college authorities, and it is this lack of grasp and understanding which causes them to slur over much of the subject-matter which it is necessary to know a little later.

As a starting point for this understanding it is essential that one grasp fully the underlying object of scientific study.

There used to be a marvelous clock exhibited in our smaller cities which had some ten or fifteen dials upon it, each dial recording some important time-element. One, for example, showed the hour of the day, another the time of the rising and setting of the sun, another did the same for the moon, while still another gave the time of the ebb and flow of the tides. There was a dial showing the day of the month, so nicely arranged that even the 29th day of February in leap year would be noted. This clock was so adjusted that there was not only the intonation of a chime every quarter-hour, but several interesting events were recorded at this same time; for instance, a cuckoo announcing the quarter-hour was followed by a rooster strutting forth and crowing, while on the hour, a tiny door at one side of the clock opened, and the twelve apostles solemnly marched across and disappeared on the opposite side, while strangest of all, these apostles did not drag their feet, but actually lifted them as they took their hourly walk.

And all of this elaborate adjustment was the result of a single clock-work running by a single winding.

A living organism is something like that clock, except that it is a thousand-fold more complicated, for man can do many times the number of things that the clock did. Now, the science of biology is directed just toward the one end of attempting to find what original mechanism makes all these complicated actions possible. In other words, in the study of biology we are attempting to find not only life's clock-work and the unit structures with which such a mechanism is built, but we also try to approach that particular place or time in the history of the universe when the first winding took place.

Chemistry presents an excellent starting-point for further explanations. In chemistry a compound is analyzed by finding the type of **molecules** that are contained within it, a **molecule** being the smallest obtainable particle of a chemical compound. The molecule, in turn, is then reduced to **atoms** of the various chemical elements, an atom being the smallest obtainable particle of a chemical element. The mind can readily conceive, however, that there are smaller particles than atoms.

As soon as we realize that the black soot which comes from a smoking-chimney and the purest of white diamonds are both composed of exactly the same chemical atoms—that is, are both pure carbon—we find we are not satisfied until some explanation of this remarkable difference can be given.

At this point we must pass to the study of **physics,** for it is physics that deals with the laws of movement and of energy. In reality, it is from the physicist, rather than from the chemist, that we obtain an explanation as to why the different chemical formulæ are what they are. The physicist has found that atoms can be broken up into very tiny particles, each fragment having the power of attracting or repelling other fragments. Such tiny particles are called **electrons.**

Knowing this we can evolve a great underlying principle that can be applied in as many different ways as was the principle of Archimedes, referred to in a former chapter.

In fact, the theory of electrons tells us not only why two elements chemically alike have a totally different appearance, but it also gives us an explanation as to why there are different chemical elements to begin with.

It has been found that if pure carbon is subjected to tremendous heat in electric furnaces, followed by the application of thousands of pounds of pressure, this carbon will become a diamond.

The scientific man, learning that this is true, immediately attempts to bring about a wider application of his knowledge for the purpose of evolving still other principles. Such an one comes to the conclusion, then, that it is quite likely that all matter is composed of electrons, and that the different forms that matter assumes are due only to varying degrees of heat and pressure.

This means that everything physical—everything that occupies space—be it wood, iron, coal, radium, hydrogen, oxygen, or what not, is quite probably composed of the same ultimate material or substance, but in each case such ultimate substance has been exposed to a different quantity of heat and pressure.

Now, the object of science is **to control nature** and to **prophesy what will occur when certain acts are performed.**

It is well to note at this point that science can never explain the fundamental **why** of anything. It can not tell why metal becomes soft when heated while an egg becomes hard. What science can do, and aims to do, is to find **how** things can be changed from what they are by performing a combination of certain very definite acts.

Just as the explanation of how chemical elements come to be what they are, was found by physicists and not by chemists, thus showing the inter-relationship of the two sciences, so man, being a complete entity made up of both the physical and the mental, must be considered in this double capacity if we are to study him scientifically.

On the physical side physics and chemistry form man's most important studies. Everyone knows that food is composed of chemical substances which, after being taken into the body, passes through many chemical changes before it is converted into new blood to keep life going. The student, however, probably does not know that Louis Pasteur, the Father of Bacteriology, was a chemist, and that the whole modern conception of medicine is based on the bacteriological findings he obtained while working on fermentation experiments in the chemical laboratory. The knowledge he there gained was later applied by Lister, who made aseptic surgery possible.

The discovery of oxygen, by a chemist, directly underlies practically every experiment in physiology that can be performed, while the great modern surgical advances are largely due to our ability to anesthetize the patient. The anesthetics used are nitrous oxide, chloroform, and ether—all products of the chemical laboratory.

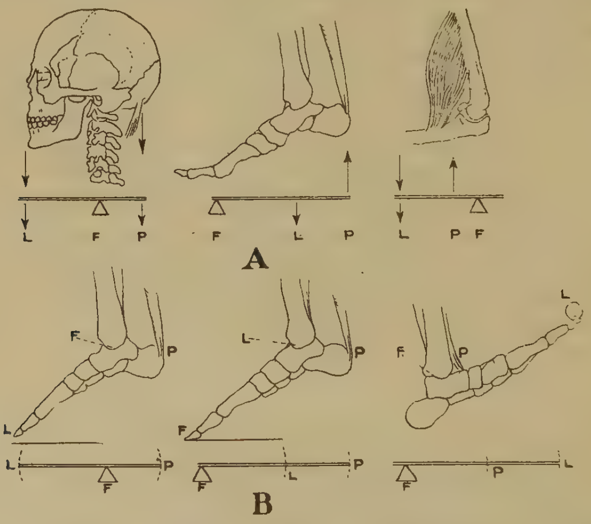


Fig. 2. Diagrams to illustrate the different types of levers in their relations to the mechanical action of muscles.
A. Comparison between head, foot and elbow.
B. Comparison between different actions of foot.

Most muscles act on bones as levers. In physics there are three types of levers recognized. In the first type (I) the fulcrum (F) lies between the place where power (P) is exerted on the lever and the point of resistance or load (L). Levers of this kind are frequently met with in the body. In A, (1) the weight of the skull tends to bend the head forward, while the force exerted by the dorsal muscles of the neck serves to keep the head in position.

In levers of the second class (II) the point on which power is exerted moves through a greater distance than the point of resistance. Speed is thus sacrificed to power. Such levers are rare in the body. An example is the body raised on the toes.

In levers of the third class (III) the point on which force is exerted, moves a less distance than the point of resistance, power thus being sacrificed to speed. This is the most common form of leverage in the body. The example A (III) is that of the elbow. Here the biceps and brachialis muscles are attached only a short distance from the elbow-joint or fulcrum, while the hand is the region on which force is exerted. A movement at the point P through a short distance will cause L to move a great distance.

The ability to analyze any product or portion of the body must lie with **analytical chemistry**, while the study of how to build up new products comes under **synthetic chemistry**. All digestion takes place by enzymes, and the enzymes of the stomach, for example, will not function unless they are placed in an acid medium, such as the gastric juice. Changes in food, or abnormalities of various kinds, may cause an excess of this acid, or may prevent a sufficient quantity of the proper quality being formed—all such changes are chemical.

The study of **physics** in its application to one's body is not so self-evident and is often the bug-bear of students. Unfortunately most of the textbooks on physics lay their greatest stress upon mechanical laws only in their industrial applications, and fail to show how these same laws apply to the human body.

The **mechanics** of the living body are, however, quite similar and much more important than all the industrial applications which can be found.

The three types of **levers** with the fulcrum in different positions is the same in the body (Fig. 2) as it is in general mechanics, and a knowledge of the exact points where stress and pull are applied, with a consequent ability to "figure out" where new growth structures will develop, is of prime importance in broken, misplaced, and re-set structures, if the patient is not to suffer untold agony and sorrow in future years.

In this connection, the laws governing **pulleys,** the combination of rolling and sliding movements of joints, as well as the principles of gravity, must be thoroughly understood; for, it is simply and solely on these principles that the various movements of the body can take place, and consequently, it is only a knowledge of such principles which can in turn make possible the correction of abnormalities of joints.

The principles governing **friction** are applied in the correction of both internal and external injuries, while experimental physiology would be impossible without a knowledge of **centripetal** and **centrifugal forces** and the laws governing **liquid and gaseous pressures.**

The laws governing liquids apply throughout the entire body in great detail, for there is scarcely a spot as large as the point of a needle anywhere in the body that liquid nourishment (blood or lymph) does not enter. Pressure in any region causes swellings, varicose veins, dropsy, and a host of other ills; while bed-sores are nothing more or less than the effect of continued pressure of blood in the same vessels of the side or back on which the person lies, gravity causing the blood to sink to the lowest level and be held there.

An understanding of the difference in **densities** makes many physiological experiments possible, which would otherwise result fatally to the patient. A solution, if it is to be injected, must not only have the proper density so as not to cause a too rapid change in the blood, but the whole subject of **osmosis, diffusion,** and **capillary attraction** must be understood before such an experiment can be intelligently applied.

The place where parasites are most likely to lodge, is largely determined by the rapidity, direction, and pressure of the blood-stream.

Hydrometers and **urinometers** for testing liquid densities are built on the principles just mentioned.

Air is a gas, and as such comes under the laws governing **gaseous pressure** and **gaseous diffusion.** When it is remembered that the whole process of life is snuffed out whenever the breathing apparatus ceases to work properly, it will be seen that the aeration of the blood to keep it red and healthy, the working of the lungs under normal and abnormal conditions (the latter in chest puncture), the being overcome by gas, externally or internally, as well as the changes in breathing at different heights and at different depths (as on mountain-tops and in submarines) ; all these can only be understood and helped by a thorough study of the laws and principles applying to gasses.

The principle of the **force-pump** makes the pumping of the heart and the one-way valves in heart and veins understandable.

All food eaten can only be reduced to blood by a burning process, called **oxidation,** so that unless the principles governing heat are understood, the processes of digestion and the consequent abnormality—indigestion—must go on unremedied.

The principles of **ventilation** in the home, office, work-shop, or sick room, make for health or disease, just as one applies them or leaves them unapplied. A window opened at the top warms the incoming air before it strikes the patient. The knowledge that warm air ascends and cold air descends lets us know that a heating plant must be placed in the basement and a cooling plant in the attic, while the principle of **evaporation** explains how outpourings of the sweat glands, by being drawn off rapidly into the surrounding atmosphere, make it possible for warm-blooded animals to retain an even temperature, regardless of varying environments.

In "chills" the body really produces more heat than ordinarily, but it is the **heat-regulating apparatus** which is out of order.

Thermometers and **hygrometers** are measuring instruments by which we are able to note the degree of heat and moisture respectively in the atmosphere. They are, of course, simply an application of some of the laws learned in physics.

Then, too, **boiling and sterilizing** make food, normally unpalatable and sometimes even injurious, palatable and non-injurious. It is sterilization also which makes antiseptic surgery possible.

The laws governing liquids under varying conditions of heat give us our basis for understanding **evaporation, condensation, distillation, conductivity, convection, radiation,** and even **plumbing and heating.** It explains why germs can be killed at a much lower temperature when there is moisture in the air (steam) than otherwise. In fact, a human being can live in a boiling-point temperature if the air is dry, but he cannot live in anywhere near so high a temperature if there is moisture.

The entire understanding of the working of the ear is a matter of physics, in that "sound" is a branch of that science. And, as the larynx is the instrument through which our vocal sounds are produced, this, too, must be studied in the light of physics.

All knowledge of the eye, such as our ability to fit glasses, operations for ocular defects, and all the instruments with which the modern oculist examines and remedies eye-troubles, are the result of direct applications of the principles of "light," which, like "sound," is a branch of physics. Any assistance in improving hearing or sight must, therefore, be looked for only in the laws of physics.

The microscope, without which practically none of our modern scientific work would be possible, is the direct application of the laws found in physics, and there cannot be a single improvement in that instrument until a new principle of physics is discovered.

Likewise, the microtome, the instrument by which we are able to cut minute sections for the microscope, could not cut with precision the thin slices that it does (1/25,000 of an inch in thickness), if it were not made in accordance with the laws of physics.

Electricity, used so much now in the treatment of disease, the X-ray, the fluoroscope, and radium—all these come under the science of physics.

That same science explains why the blood-platelets gather along the blood-vessel where the blood stream is slowest; it explains how **coagulation** is thus assisted so that we do not bleed to death when wounded; it tells us why one can crawl over thin ice when walking across the same ice-sheet would be impossible; why we can safely crawl on the floor in a room filled with smoke, when standing erect would be fatal; it makes an intelligent understanding possible of how to drain wounds; it tells us why water-pipes burst when the water in them freezes; it tells us why a quilt or comforter of cotton is warmer than a woolen blanket; it tells us why men's voices are different from those of women's, and why the pupil of the eye can accommodate itself to changing distances and intensity of light; and, just as it tells us that an electric bell will not ring until the proper connection is made, so it makes possible the locating of lesions in the body by noting where nerve connections are functioning properly and where they are not.

Probably the **mathematical sciences** may seem somewhat remote from the study of life in general, yet **calculus** is needed in the study of physical chemistry, and the laws of **refraction** in the fitting of glasses. The relationships of structures in the body must be studied both as to their **quantity** and **quality**. The various names given to the different forms and shapes of the parts of the body are largely taken from **geometry.**

Surely so remote a subject as ancient **Greek** is far removed from modern scientific study, and yet the student need but turn to the glossary of this book, and go over the thousands of names there given, to see that ancient Greek is not only valuable, but extremely essential; for, practically every name that plants and animals possess comes from the Greek, and unless the **meaning** of the word itself is known, the entire subject-matter becomes pure memory work.

The reason each student must draw a picture of what he sees in his laboratory experiment, is to force him to observe so well and so accurately that he can make a drawing of a structure so accurate, that another may in turn recognize the object from the drawing. Drawing a picture of what he sees also forces the student to keep the subject in mind for a greater period of time than would otherwise be the case, and gives him a definite graphic mental picture of what he has seen.

A knowledge of **English** makes it possible for the student to present a word-picture of the same matter that the drawing presents. **A description** is, therefore, demanded of the student in addition to the drawings, thus again causing him to call to mind all that he has seen and noted. This not only means that the repetition thus forced upon him will cause him to remember the subject-matter the better, but it means that he learns to do that particular thing upon which much of his future reputation as a professional man depends, namely, to prove to others in good clear and telling language what he knows.

The mere gathering of facts is of no more value than the mere gathering of bricks. The important thing in science is to be able **to coordinate the facts** that one finds, and to read into these facts their real **meanings.** Meanings, however, require the use of the intellect, and the laws which govern the intellect are embodied in that branch of study called **philosophy.** The most important philosophic studies for the scientific student are **logic, psychology,** and **ethics.**

Every valid conclusion which anyone may form must be built up logically. Logic is merely **the grammar of reason.** In fact, every diagnosis that a medical man makes, must be built entirely upon logic if it is to be worth anything, or to stand the test of truth.

The study of the way in which the mind works is called psychology, and no man can intelligently study, nor clearly understand, any of the abnormal workings of the human mind, unless he first knows the normal. He can know little about mental or nervous diseases unless he knows the way in which the mind works when it is not diseased. In his study of **neurology** the medical student follows the various nerve-tracts of brain and spinal cord, but he cannot understand the real meaning of these nerve-tracts unless he knows his psychology. He will become a follower of fads and fancies while he misses the underlying truths and facts that the real scientific man should have.

From the philosophical realm we obtain the validity of our ethics. Ethics is the **science of conduct.** We know that holding an air-breathing animal under water will drown it. And just as death to the animal follows such an act, so, too, many of our acts bring a definite punishment of some kind with them. It is to know what acts bring punishments, so as to know what acts to avoid, which is the distinct province of ethics. In other words, it helps us to arrange a definite "philosophy of life" for ourselves.

And lastly, one or two **modern foreign languages** should be known in order that we can the better obtain another angle and another point of view to the many possible explanations that the same facts may seem to prove. One has but to read through any ordinary school textbook of science to find what an overwhelmingly large number of foreign names and papers are there quoted. This means that no one can deem himself a master of his subject unless he knows at least many of the thousands of observations that have been made by the great scientific minds of other lands. Unless he knows this, he is bound to spend a large part of his life in the attempt at proving or disproving many things that have already been proved or disproved by others. He is wasting the time which should be given to more valuable work.

From what has been said above it will be seen that all the sciences must be studied to throw light on the different workings of the body.

At this point it is necessary for the student to grasp the fact that every living thing must be considered as a complete unity, like the clock mentioned. and that every organ and every part of an organ which a living thing possesses, is definitely connected to, and with, every other part of the body.

One may suffer from headaches, or with eye-trouble caused by displaced bones in the feet, which in an indirect way press against nerves connecting with the head; or, one may have a backache or earache, or even rheumatic difficulties, due to ulcers beneath the teeth.

It is for reasons such as these that it is as necessary for a dentist as well as an oculist to study biology, and learn the unity of the living being. For there is no more reason for a student of dentistry to confine all his study to the teeth alone, or an oculist to the eye alone, than it is for a nerve specialist to study the nerves alone. Any such one-sided study leaves out of consideration the most important factors necessary to a legitimate diagnosis. And, with a wrong diagnosis, the treatment is bound to be wrong, or at most, mere guess-work.

It is well also for the student to bear in mind that, though he may not immediately see the relationship of some things to the general course he is taking, it does not follow that such relationship does not exist.

One can learn to start and stop a locomotive in twenty minutes, but this does not make one an engineer. It takes years to do this. It is not when all things go well that the expert is called in, but when things go wrong. This is true of the engineer, the physician, the dentist, the lawyer, and other professional men. And it is only he, who knows the relationship of all the parts, who can hope to be an expert.

In conclusion, the student should remember that all college courses are arranged on a **minimum basis.** That is, the work laid out for the student is the **least amount of work he can do and yet obtain a passing grade.** It is, therefore, only **the student who actually does more than is required, who deserves any credit worth mentioning.**

CHAPTER IV.

THE FROG

The frog lends itself to laboratory work in biology probably better than any other animal. It is sufficiently common so that it is at least somewhat familiar to the student, and it can be procured practically at any season of the year. It is a **vertebrate** (Latin—**vertebratus**-jointed) which means it has a back bone, and an **amphibian** (Greek **amphi**=both, **bios**=life), meaning that it lives a double life. This latter statement refers to the animal's inability to live either on land alone or entirely submerged in water. This inability to live entirely in the air or in water is well shown by the fact that if the frog's skin becomes dry, as it does when the animal is away from water and in a dry atmosphere, the animal dies, because the skin is then no longer capable of serving as an organ of **respiration** (Latin **re**=back+**spiro**=breathe). Contrariwise if it be constantly immersed in water it will also die, because it must breathe air.

The particular **species (Rana pipiens)** that we are describing (though any other of the common forms would answer the same purpose) is found in or about fresh-water lakes, ponds, or streams. The species is fairly well distributed over the entire North American continent, except the Pacific Slope.

Everyone has noticed the longer and stronger hind legs of the frog and the squatting position it assumes on land, as well as the rapidity with which he leaps into the water when disturbed along the banks. If one observes him while in water that is beyond his depth, it will be noted that the hind legs hang out straight and the tip of the nose is exposed to the air. Should he be disturbed while in this position, the hind legs are **flexed,** (L. **flecto**-bend) which throws the body downward. The fore legs are used in arranging the direction in which the animal will go; the hind legs are then **extended,** (L. **ex**=out+**tendo**=stretch) completing the movement which forces him forward.

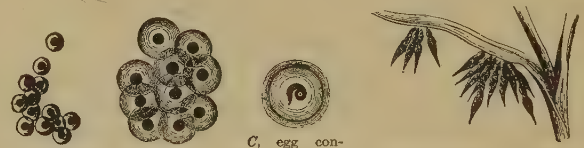
Everyone also knows the sound of croaking frogs at night, especially when the atmosphere becomes damp, though it is not so generally known that the frog croaks far more frequently during the breeding season than at other times. The croaking can be accomplished both in and out of the water. The croaking under water is produced by the air from the lungs being forced past the **vocal cords** into the cavity of the mouth, and then back again into the lungs.

There is another reason why the frog may be considered as leading two lives (Fig. 3) beside the fact that it needs both air and water, and that is that it lives a different **type of life when young** than when grown. This comes about as follows: The eggs of the female frog are almost always laid in water and hatched there. Little tadpoles develop from these eggs and breathe by **gills** in the **larval** ( ) condition.

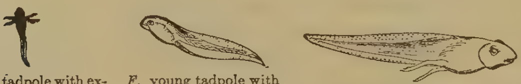
Some species of frogs retain these gills all through life, even though lungs may be present in the adult forms. The tadpole gradually develops into the mature frog, losing its tail and developing the long hind, and the short fore legs so familiar in the adult animal.

EXTERNAL FEATURES

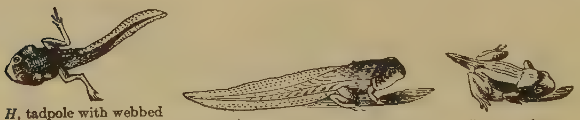
It is essential that one examine quite carefully the **external structure** of any plant or animal one may wish to study; for, unless this knowledge is borne in mind, **internal structure** cannot be **interpreted** correctly. It is well also to keep in mind our own bodies, and to observe similarities and differences wherever they may occur in animals and plants.



A, eggs before they are laid *B*, eggs after they are laid *C*, egg containing young tadpole *D*, young tadpoles attaching themselves to a plant



E, young tadpole with external gills *F*, young tadpole with internal gills *G*, young tadpole with hind legs



H, tadpole with webbed feet *I*, tadpole with legs and arms *J*, young frog

Fig. 3. Eggs, Tadpole, and Adult Stages of Frog.
(After Brehm and other authors.)

It will be noted immediately, that the frog has no neck. The head is broadly united to the **trunk.** The eyes protrude somewhat, but can readily be withdrawn into the **orbits.** A pressure put upon the eyes if the mouth of a frog is open will extend the **inner membrane lining** of the **roof** of the mouth quite prominently, showing that the orbit, or eye socket, is not separated from the mouth by any of the bones of the skull as in ourselves. The dark oval opening of the eye, the pupil, is surrounded by the **iris,** a more brightly colored ring. There are upper and lower lids, the upper one moving but slightly, the lower one thin and transparent, and capable of covering the entire eye. This lower eyelid is different from that of most animals, and this type of lid will be met with again in other animal forms to be studied. The **nictitating membrane** ( ) is separated from the lower lid (Fig. 4), but appears to form a continuation. In birds, for example, this membrane is also very thin and can be thrown over the eye from the **inner angle** of the orbit. Behind the eye is a more or less circular area called the **tympanic**

membrane, (   ) which covers the **ear drum.** There is a slight **prominence** in the center of this membrane produced by one of the small bones called the **columella** (   ). This bone connects with the **inner ear** and when any sound-wave strikes the tympanic membrane the vibrations are communicated through this bone into the internal ear. This gives rise to the **sensation of hearing.** On the inner side of the tympanic membrane we find a little cavity known as the **Eustachian tube** (   ), which opens internally into the mouth. There is no **external ear** present as in ourselves.

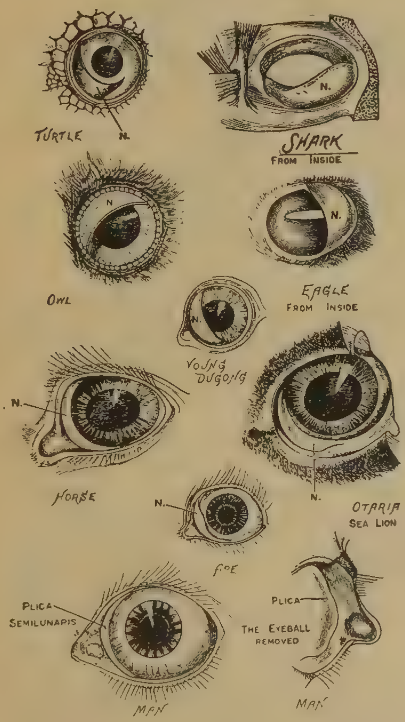


Fig. 4. Examples of Nictitating Membranes. (From various authors.)

The two openings immediately **above** and **behind** the tip of the nose are called **nostrils** or **external nares.** Sometimes, in **front** of the eyes there is a little light area known as the **brow-spot,** which was connected with the brain in the **embryo** (   ). The brow-spot is a feature of considerable interest from the fact that in the **embryonic development** of the frog, it connects with a peculiar **outgrowth** of the brain known as the **epiphysis** (   ) or **pineal gland.** This is supposed to be a **rudiment** (   ) of a stalk which formerly connected with the **medial eye** (   ) which still persists in certain forms of **reptiles** (Fig. 5), (   ). The nostrils are guarded by **valves** which open and close during **respiration.**

The mouth extends from one side of the head to the other, and the **anus** (   ) is situated at the **posterior** (   ) end of the body. The **fore limbs** are divided into an **upper arm,** a **fore arm,** and a **manus** (   ) or hand, the latter possessing four **digits** and the so-called **thumb,** a **rudiment** of the fifth. In the male, the **inner digit** is thicker than the corresponding one of the female, especially during the breeding season. The entire fore arm is also relatively thicker in the male than in the female.

The hind limbs are well **adapted** for jumping and swimming. These are divided into three portions, the upper portion known, however, as the **thigh,** the middle as the **crus** or **shank,** and the distal (   ) portion as the **foot** or **pes.** The foot is well developed, there being five toes and the rudiment of a sixth, called the **prehallux** (   ), situated on the inner side of the foot. The toes themselves are connected with a web, making the foot quite efficient as a swimming organ. There are also small **cushions** called **subarticular pads** (   ) between the bones of the toes.

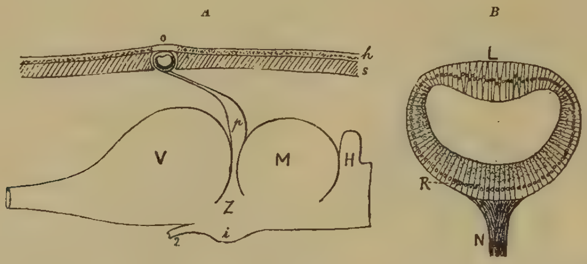


Fig. 5. Pineal eye of a Lizard; diagrammatic. *A* brain and upper wall of the skull, the latter cut through; *B*, pineal eye alone, in section. *V, Z, M, H*, cerebrum, thalamencephalon, optic lobes, cerebellum; *h* skin, *s* roof of skull, *o* unpigmented portion of skin below which the pineal eye lies, in a hole in the roof of the skull; *p* epiphysis, *i* hypophysis, 2 optic nerve. *L* lens, *R* retina, *N* nerve of pineal eye. (After Boas.)

The skin is smooth and loose, containing large black **pigment spots** (   ) and some green and golden pigments as well. As with other **vertebrates,** the skin has two layers, an outer called the **epidermis** (   ) and the inner, the **dermis** (   ). Nothing similar to **hair** or scales can be found on the frog. There are large **mucous glands** (   ) in the skin which keep the surface slimy and there are also some **poison glands secreting** (   ) a whitish fluid, supposedly for **defensive** purposes. Behind the eyes there are usually two light colored **ridges** formed by a thickening of the skin and called the **dorso-lateral dermal plicae** (   ) or folds. There may be some smaller, **irregular, longitudinal folds** (   ) of skin between these. It will also be observed that the color of the skin is much darker on the upper or dorsal surface than below, where it is almost white.

INTERNAL STRUCTURE

As with us, the various **organs** (   ) and **tissues** (   ) of the frog's body are supported by an **internal skeleton** of bones. This is called an **endoskeleton** (   ) to distinguish it from such types of animals as the **crayfish** which have their entire skeletal structure on the **outside of the body,** forcing that animal to grow an entirely new skeleton whenever the animal itself grows larger than its skeleton-jacket will stretch. The higher forms of animals all have endoskeletons. The different parts of the body are moved by the action of **muscles,** which in turn are **innervated** (   )

by nerves. To know the **internal structure** of an animal one must know all that can be known in regard to the following systems:

1. Digestive
2. Circulatory
3. Respiratory
4. Excretory
5. Nervous
6. Skeletal
7. Muscular
8. Reproductive.

After an **incision** is made along the **mid-line** (Fig. 6) of the **ventral** ( ) **surface** of the animal from the **lower angle of the jaw** to its most **posterior end,** the internal organs are seen. These are called the **viscera** ( ). The cavity in which they are found is known as the **coelom** ( ) or **body cavity.**

If the animal has just been chloroformed, the **heart** will still be beating. The heart is contained in a sac-like structure called the **pericardium** ( ).

Surrounding at least a portion of the pericardium, are three prominent **lobes** of the **reddish-brown liver,** while the **lungs,** looking like small strawberries, lie, one on each side, near the **anterior** end of the **abdominal** cavity.

The **stomach** is easily recognizable, together with the coiled **intestine attached** to it.

The **kidneys** are **flattened reddish bodies** attached to the dorsal body wall.

If it is the breeding season, and the frog is a female, almost the entire body-cavity may be filled with thousands of **eggs.** The eggs in turn are contained in a **film-like covering** known as the **ovary** ( ) and **oviducts** ( ), the latter organs serving as tubes through which the eggs leave the body. If the specimen should be a male, the two **testes** ( ) will be suspended by little **membranes** at the side of the **digestive canal** (t, Fig. 6). The entire lining of the abdominal cavity in all the higher forms of animals is called the **peritoneum** ( ). When one or two layers of this peritoneum **suspend,** or hold up an organ, such as the digestive canal and the reproductive organs, such suspending peritoneum is called a **mesentery** ( ).

THE DIGESTIVE SYSTEM

It will be noticed that the tongue is what is called **extensile** ( ), that is, it can be thrown forward and outward. There is a sticky substance secreted on the tongue which causes objects with which it comes in contact to adhere. It is also interesting to observe that unless an object is moving, the frog pays no attention to it.

The **mouth** or **oral opening** is relatively large. The opening on the interior is called the **buccal** ( ) cavity. There are teeth on the **maxilla** ( ), **premaxilla** ( ), and **vomer bones** ( ). These assist in **holding**, but

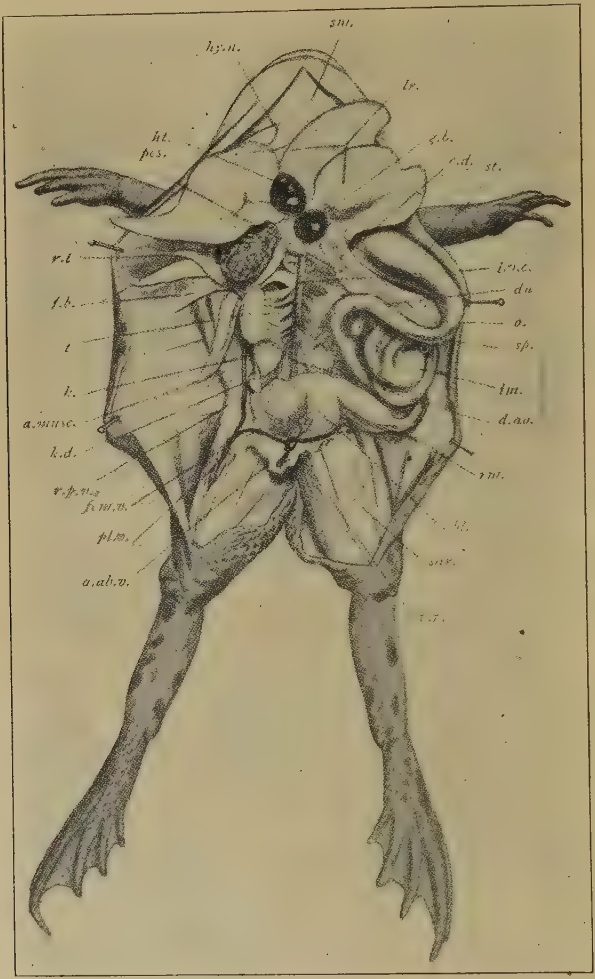


Fig. 6. A Male Frog Dissected from the Ventral Side.
a.ab.v., Anterior abdominal vein, cut short, ligatured, and turned back; *a.musc.*, cut edge of abdominal muscles; *bl.*, urinary bladder; *c.d.*, common duct of gall-bladder and pancreas; *d.ao.*, dorsal aorta; *du.*, duodenum; *f.b.*, fat body; *fem.v.*, femoral vein; *g.b.*, gall-bladder; *ht.*, heart; *hy.n.*, hypoglossal nerve; *im.*, ileum; *i.v.c.*, inferior vena cava; *k*, kidney; *k.d.* kidney duct with vesicula seminalis; *lr.*, liver; *o*, point at which *c.d.* enters the duodenum; *pcs.*, pancreas; *pl.v.*, pelvic vein; *r.l.*, right lung; *rm.*, rectum; *r.p.v.*, renal portal vein; *sar.*, sartorius muscle; *sm.*, mylohyoid muscle; *sp.*, spleen; *st.*, stomach; *t.*, testis; *v.v.*, vesical vein. (After Borradaile.)

not in **masticating** the food. Immediately back of the tongue on the **floor** of the mouth is a narrow slit called the **glottis** ( ) leading to a tube passing to the lungs, and directly behind the glottis, a larger opening is found, leading to the **oesophagus,** which empties into the stomach. The stomach itself is **crescent-shaped,** lying mostly on the left side of the body. The larger anterior portion is called the **cardiac end** ( ), while the **constricted** or posterior portion, meeting with the intestine, is known as the **pyloric** ( ) end.

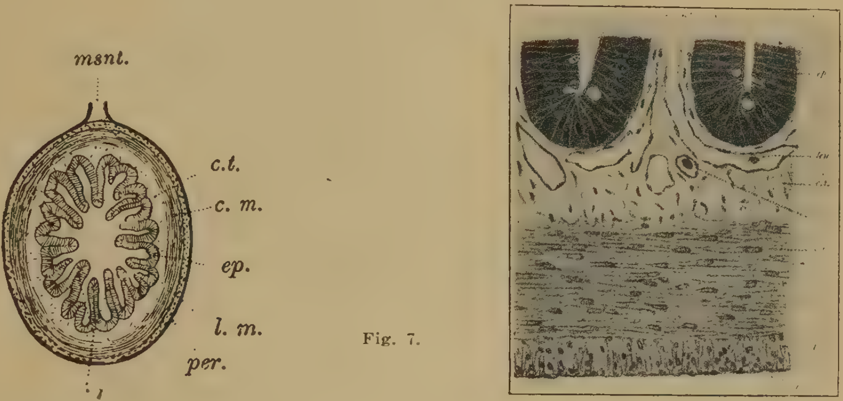


Fig. 7.

A. A Diagram of a Transverse Section Through the Ileum of a Frog.
c.m., Circular muscle layer; *c.t.*, submucosa; *ep.*, epithelium which lines the gut; *l.m.*, longitudinal muscle layer; *msnt.*, mesentery; *per.*, peritoneum; *rid*, longitudinal ridges of ileum composing mucosa.

B. A Portion of the Section Shown in A, More Highly Magnified.
b.v., Blood vessel; *c.t.*, connective tissue of mucous membrane or submucosa; *c.m.*, circular layer of muscle fibres; *ep.*, epithelium; *g.c.*, goblet cell; *l.m.*, longitudinal layer of muscle fibres; *lct.*, "lacteal" or lymph vessel of the intestine; *leu.*, leucocyte or lymph corpuscle; *p e.*, peritoneal epithelium. (After Bourne.)

The first portion of the intestine, a sort of U-shaped band, is known as the **duodenum** ( ). The several coils following it are the **intestine** proper. This intestine finds its way into a large but short chamber known as the **rectum,** which in turn communicates with the **exterior** through what is called the **cloacal** opening ( ). The walls of the stomach are composed of five layers (Fig. 7), the outer portion quite thin, called **peritoneum,** then two **muscular layers,** the outer being called the longitudinal, and the inner the circular muscle layer, followed by a **spongy division** called the **submucosa** and an **inner folded mucous layer,** the **mucosa** itself. This latter is made up of **glands** lying in **connective tissue.** These glands are longer at the cardiac than at the pyloric end. The inner layer of the intestine, the mucosa, is considerably folded and consists of **absorptive and goblet cells.** The **urinary bladder, reproductive ducts** and rectum, open into the cloaca.

The **digestive glands** themselves are the **pancreas** and **liver,** the former lying immediately **between** the **duodenum** and the **stomach.** It is a much branched **tubular gland,** secreting an **alkaline** digestive fluid and empties into the **common bile duct.** The three-lobed liver, already mentioned, also secretes an alkaline digestive fluid, known as **bile.** This is carried by the little **bile capillaries** into the **gall bladder where** it is stored until food enters the intestine, when it passes into the duodenum through the common bile duct. Digestion begins in the stomach.

According to Latter, "the alkaline fluid secreted by the mucosa layer of the oesophagus and the **acid gastric juice** secreted by the glandular walls of the stomach digest out the **proteid portion** of the food by means of a **ferment,** ( ) called **pepsin,** which changes proteids into **soluble peptones.** The food then passes through the pyloric constriction into the intestine. Here it is attacked by the **pancreatic juice** and the bile. The pancreatic juice contains three ferments: (1) **trypsin,** which converts proteids into peptones; (2) **amylopsin,** which converts starch into sugar; and (3) **steapsin,** which **splits up fats** into **fatty acid** and **glycerin.** The bile **emulsifies fats** and converts **starch** into **sugar.** The intestinal wall produces a secretion which probably aids in converting starch into sugar.

"**Absorption** begins in the stomach, but takes place principally in the intestine. The food substances which have been dissolved by the digestive juices are taken up by the mucosa layer, passed into the **blood** and **lymph,** ( ) and are **transported** to various parts of the body (C, Fig. 8). The undigested particles of food pass out of the intestine into the cloaca and are then discharged through the anus as **faeces.**"

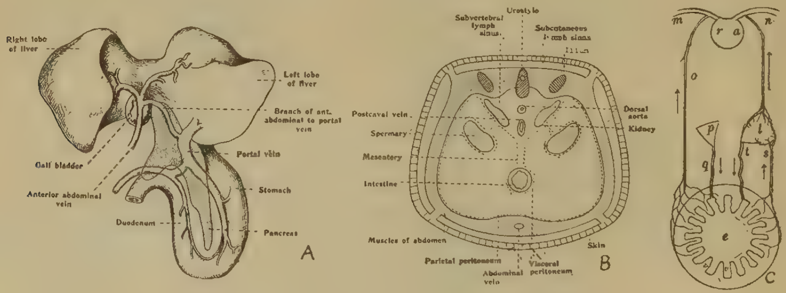


Fig. 8. Diagrams of Important Relationships.

A. The relation of the hepatic portal system to the stomach, intestine, pancreas and liver.

B. Diagrammatic transverse section through the abdominal region of a frog.

C. Diagram of the two main channels by which food enters the general circulation in mammals. *e*, intestine with villi; *v*, *v*, in its walls; *r a*, right auricle of the heart; *m*, postcava; *n*, precava; *o*, thoracic lymph duct; *p*, pancreas; *q*, pancreatin duct; *r*, hepatic vein; *s*, portal vein; *t*, bile duct from *l*, liver; arrows indicate the course of secretions entering the intestine, and of the absorbed food departing therefrom.

(A, after Howes; B, after Parker; C, from Needham's *General Biology*," by permission of The Comstock Publishing Co.)

The absorbed food is used by the frog to build up new **protoplasm** to take the place of that consumed in the various life activities, and to increase the size of the body. Food is stored up in the liver-cells as

glycogen, a **carbohydrate** similar to starch and often called "**animal starch.**" The absorbed food is conveyed to the liver by the portal vein and there converted into glycogen, pending the demands of the general tissues of the body. As occasion arises it is converted into more soluble material, a sugar, and sent into the main bloodstream via the hepatic veins and inferior vena cava. Fat globules are also contained by the liver cells. The storage function of the liver is one of considerable importance, especially during hibernation and at the breeding season; the weight of the organ exhibits a well-marked seasonal variation in accordance with the amount of reserve food contained. The details of this phenomenon have been worked out by Alice Gaule in **Rana esculenta.** The breeding season of this form is in May, June, and July. The table shows the average weight of the liver in the two sexes month by month.

"It will be observed that the liver is most depleted in both sexes in June, the middle of the breeding season, and that it reaches its maximum weight in September when the system has recovered from the exhaustion of spawning. Throughout the winter the reserves are being steadily used up, with no recovery by the female, the average weight of whose liver is greater than that of the male, but with a slight recovery in March and in May by the male. It is probable that this general difference depends upon the fact that the ovaries of the female make a great and continuous demand upon her system throughout the whole period of maturation, so that in spite of renewed feeding in the Spring there is no recuperation in the liver. In the male, however, there is no such continuous drain but rather a sudden call upon the reserves at the actual time of pairing—a call due not only to the discharge of the spermatozoa but also to the muscular exertions of the male at that season. This call is marked in vigor by the sudden reduction of the liver to rather less than half its weight in June.

Month	Weight of male liver	Weight of female liver
January	10 grms.	13 grms.
February	10	12.5
March	13	11
April	10	10
May	12	9
June	5.5	7.5
July	7.5	11
August	6	12
September	22.5	27
October	18	25
November	22	25
December	18	22

"Reserves of food are also laid up in the fat-bodies. These have no direct connection with the digestive system, but may conveniently be dealt with here. They are bright yellow, finger-like bodies grouped in front of the testes or ovaries as the sex may be. They develop from the anterior portion of the genital ridges whose posterior portions alone give rise to the sexual organs. In the autumn they are of great size and loaded with fat-cells, a certain amount of lymphatic tissue being also present. In the spring they are much reduced. It is probable that they also perform other functions at all seasons of the year, but on this point we have no precise knowledge."

GLANDS

Glands may be conveniently classed into two groups:

Exocrine glands, that is, glands whose products are used externally or on substances entering the body, and which generally leave by way of ducts.

Endocrine glands, that is, glands whose products act on the body itself, not on substances brought into it. This type of gland generally has no duct; or if so, as in the case of ovaries and pancreas, the "endocrine" portion of the secretion is absorbed by the blood vessels and does not leave the gland by way of a duct. The term "ductless glands" has been used to designate these glands, but has been found inappropriate. The products of the endocrine glands are known frequently as **"internal secretions,"** and are composed of active agents similar to enzymes. The name of **"hormone"** (excitant) has been given to these agents, which differ from enzymes primarily in that their activity is not destroyed by boiling.

It has been found, however, that the action of the endocrines may be both **stimulatory** and **inhibitory,** as, for instance, in certain experiments on tadpoles which were fed with thymus and thyroid gland. Gudernatsch (1912-14) found that the thyroid food stimulated development and inhibited growth, while thymus stimulated growth and inhibited development. Thyroid-fed tadpoles matured in four weeks, as contrasted with the normal period of twelve weeks, but were dwarfs and pigmies in size; while thymus-fed tadpoles were gigantic in size, but after sixteen weeks showed no indication of transformation, in fact, had not yet developed their hind legs. From certain other experiments on the sexual glands it has been similarly concluded that the internal secretion from the sex glands (specifically that of the interstitial cells) acts both as a stimulant to the body so that it will develop the characteristics pertaining to its proper sex, and as an inhibitor in suppressing those of the other sex. The excitant has been named **hormone,** the inhibitor **chalone.**

The products of the various endocrines are regulatory in nature, and control or affect such processes of the body as growth, puberty, secondary sexual characters, blood pressure, metabolism, distribution and concentration of substances, muscle tone, blood sugar, etc. Instincts, emotions, mental and psychic states are stimulated, inhibited and complicated by endocrine action.

The two **thyroid glands** are situated on either side of the **hyoid,** and secrete quite a quantity of iodin. In man, its atrophy is associated with the disease called **cretinism** ( ) where certain parts of the body, such as the head, may become very large. Cretins are almost always idiots.

The two **thymus glands** ( ) lie one behind each tympanum. They are small and oval in shape, usually reddish in color, and are placed directly beneath the **depressor mandibular muscle.** The thymus, like the thyroid, diminishes in size with age.

The **adrenal bodies** ( ) are little bands of a yellowish color extending along the mid ventral surface of the kidneys. They secrete **adrenalin,** a substance necessary for the life of the animal. This substance is used to a considerable extent in medicine at the present time as it will cause a contraction of the blood vessels and raise the blood pressure after injection. However, a little later a reaction sets in, and a lowering of blood pressure follows.

The **spleen** ( ) is a reddish organ lying immediately dorsal to the anterior end of the cloaca. It is supposed to act as a sort of filter for the blood. The old corpuscles are destroyed and new colorless ones are formed. It must be remembered that all that is known in regard to the ductless glands demonstrates that they are of vital importance, but that no absolute conclusions can be drawn as to definite functions of any of them; for, while one or two of their functions are known, there are probably many more functions that are not yet even dreamed of.

THE CIRCULATORY SYSTEM

It is essential that the student grasp the fact that there are several **types** of circulation. The **systemic proper** is that closed system of blood vessels by which the blood leaves the heart and passes through the large arteries into the capillaries to carry nourishment to every point in the body (Fig. 9). These **arterial** capillaries then meet with the **venous** capillaries, and waste-matter is collected in the blood and carried by the veins into two anterior and one posterior **venae cavae** by which the blood is returned to the heart.

The heart itself, however, must have blood vessels carrying nourishment to the heart-walls just as an engine run by steam and supplying water to different parts of a building, must have water supplied to its own boiler in order that the steam which gives the engine its power may continue to be generated.

The heart muscle, which is the engine of the body, must similarly have its supply of blood to its own walls in order that the heart may be able to pump the blood to all parts of the body after it has entered the heart from the lungs where it was **aerated.** The blood sent to be aerated forms the second type or **pulmonary circulation.** The digested food which the individual has absorbed must now be taken **into** the blood and be made a part of that blood, so that there is a replacement of lost substances. This explains why the blood which goes to the digestive tract by the **coeliac axis** passes through **two series of capillaries before returning** to the heart:

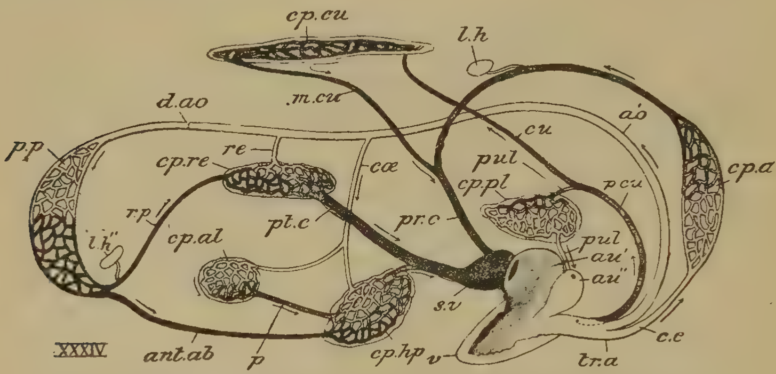


Fig. 9. Diagram Representing the General Course of Blood in the Frog and the Principal Sets of Capillaries (*cp.*) Through Which the Blood Flows.

The vessels through which impure blood goes are dark, while those carrying pure blood are left unshaded. The arrows indicate the direction of blood flow. *ant.ab*, anterior abdominal vein; *ao′*, aorta; *au′*, right auricle; *au″*, left auricle; *c.c*, common carotid artery; *cœ*, cœliaco-mesenteric artery; *cp.a*, anterior systemic center; *cp.al*, alimentary center; *cp.cu*, cutaneous center; *cp.hp*, hepatic center; *cp.p*, posterior systemic center; *cp.pl*, pulmonary center; *cp.re*, renal center; *cu*, great cutaneous artery; *d.ao*, dorsal-aorta; *l.h′*, anterior lymph heart; *l h″*, posterior lymph heart; *m.cu*, musculo-cutaneous vein; *p*, hepatic portal vein; *p.cu*, pulmo-cutaneous vein; *pr.c*, precaval vein; *pt.c*, postcaval vein; *pul*, pulmonary vein; *re*, renal artery; *rp*, renal portal vein; *s.v.*, sinus venosus; *tr.a*, truncus arteriosus; *v*, ventricle. (After Howes.)

First, into the capillaries of the intestine where it receives the nutriment absorbed from the food; and, after being collected into the large portal vein, enters the liver.

Second, after entering the liver the portal vein breaks up into another system of capillaries within that organ.

After the blood has passed through the liver this second set of capillaries unites to form the **hepatic vein** which empties into the large posterior vena cava leading to the **sinus venosus.** This whole system, where veins break up into capillaries but are again united to form a second vein, is called a **portal system.**

Part of the blood that goes to the legs also has a double system—first entering the capillaries in the leg muscles and on its way back passing through the kidneys where it is broken up into capillaries. The blood that takes this route returns from the leg through the **renal-portal vein,** but the rest of the blood from the legs is diverted to the **abdominal vein** which passes through the liver (but not the kidneys) on its way to the heart.

Now, just as has been explained in regard to the necessity of the heart having an arterial supply of blood to its own walls in addition to that which it pumps from its cavities, so the liver and kidneys must also

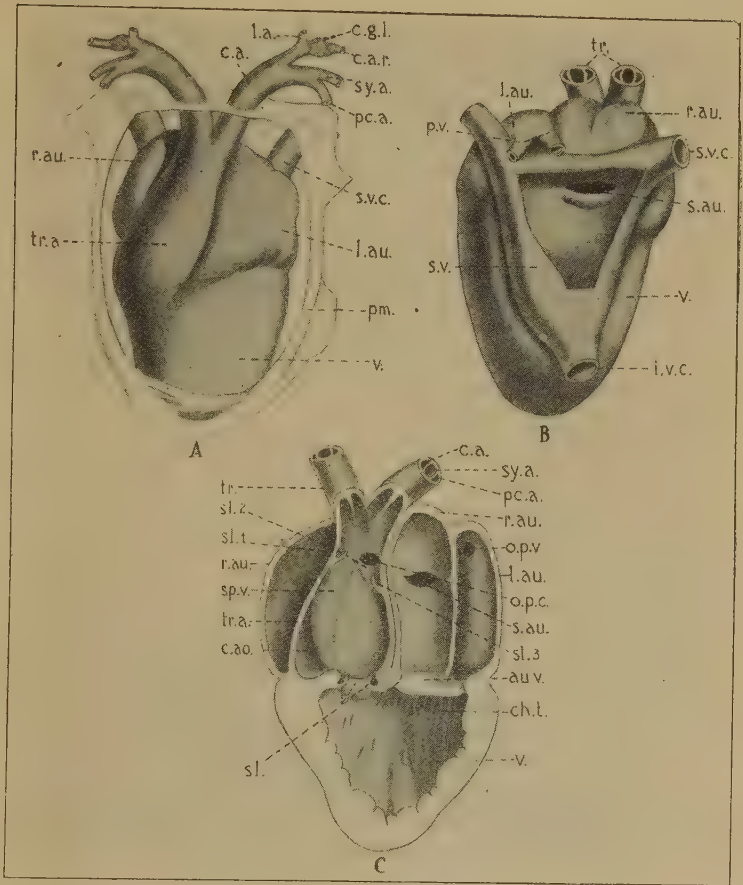


Fig. 10. The Frog's Heart.

A, seen from the ventral side; B, from the dorsal side; C, heart opened and viewed from ventral side. (The ventral wall of the truncus, ventricle, and auricles has been removed).

A. *c.a,* carotid arch; *car,* carotid artery; *c.gl,* carotid gland; *l.a,* lingual artery; *pc.a,* pulmocutaneous arch; *pm,* pericardium; *r.au, l.au,* right and left auricles; *s.v.c,* superior vena cava; *sy.a,* systematic arch; *tr.a,* truncus arteriosus; *v,* ventricle.

B. *i.v.c.,* inferior vena cava; *p.v.,* pulmonary veins; *r.au., l.au.,* right and left auricles; *s.au.,* opening from sinus to right auricle; *s.v.c.,* superior vena cava; *s.v.,* sinus venosus; *tr'.,* branches of truncus cut across; *v.,* ventricle.

C. *au.v.,* Auriculo-ventricular valves; *c.a.,* carotid arch; *c.ao.,* cavum aorticum; *ch.t.,* chordæ tendineæ; *l.au.,* left auricle; *o.p.v.,* opening of pulmonary vein; *o.pc.,* opening of dorsal division of synangium, by which blood passes from the cavum pulmocutaneum to the pulmocutaneous arch; *pc.a.,* pulmocutaneous arch; *r.au.,* right auricle; *s.au.,* sinu-auricular opening with valves; *sl.,* first row of semilunar valves; *sl'.,* semilunar valves of second row; *sl'*.1, the semilunar valve from which the spiral valve starts; the line points to a small portion of the valve which has been cut open; *sl'*.2, small semilunar valve at end of cavum pulmocutaneum; *sl'*.3, a small part of a large semilunar valve, of which the rest extends across that portion of the front wall of the truncus which has been removed; *sp.v.,* spiral valve; *sy.a.,* systemic arch; *tr.a.,* wall of truncus arteriosus; *tr'.,* one of the two bundles of arteries into which the truncus divides; *v.,* ventricle. (Redrawn from Borradaile.)

have their own supply of blood to feed the liver and kidney substance, in addition to that received from their respective portal veins.

All the blood coming from the heart, and passing directly back to the heart, whether it flows through the portal, renal-portal, abdominal or other veins, is classified as the **systemic circulation.** This is to be distinguished from the **pulmonary circulation,** which deals with the blood which, having been returned by the veins to the heart, is now sent to the lungs to be purified and aerated. This blood leaves the heart **ventricle** through the pulmonary arteries and is returned to the heart **auricle** through the **pulmonary vein.**

It is interesting to note, that in the frog, a part of the already-used-blood (venous blood) which in the human being all goes to the lung through the pulmonary artery, passes through the **cutaneous artery,** a branch of the pulmonary, to the skin under the arm, where it is also purified by the oxygen in the water. It will be remembered that the frog needs **both air and water** for breathing purposes and breathes through both lungs and skin.

The frog's heart is composed of three compartments (Fig. 10), instead of four, as in the higher forms of animals. The blood that has been purified in the lungs flows into the **left auricle** through the pulmonary vein and is thus kept separate from the impure blood in the right auricle; but, as there is only **one ventricle,** and as blood is **always received by the auricles,** and **always expelled from a ventricle,** the impure blood from the right auricle, as well as the pure blood from the left auricle, is all emptied into one ventricle so that it is bound to intermingle. However, the blood from the right side is a little more impure than on the left, because the left side is **directly** connected with the left auricle and it is the left auricle which has the purest blood. The pure and impure blood are also kept partly separated by various irregular muscular partitions called **trabeculae** extending through the ventricle.

The action of the heart is as follows: The two auricles filled with blood contract at the same time, thus forcing arterial and venous blood into the ventricle. Here the two kinds of blood are kept from mixing by the muscular trabeculae just mentioned. At the **systole** of the ventricle, the venous blood, which lies nearest the bulbus arteriosus, is first forced forward. This takes the most direct course through the wide and short pulmonary arteries which are practically empty at the time. The mixed arterial and venous blood follows the next easiest course through the aortic arches, while the last blood to leave the ventricle (the pure arterial blood), can only go to the carotids, where the resistance is greater on account of the small size of the vessels and the obstacles presented by the carotid glands.

Blood usually looks red. This is due to the large red corpuscles (Gr. erythrocytes=erythros—red+cytos=cell). The redness itself is due to what is called **haemoglobin,** a chemical substance contained within the corpuscles. There are also white corpuscles called **leucocytes** (Gr. leukos=white+cytos=cell) in the blood. These are often able to force themselves through the walls of the capillaries and then wander about through the tissues. There is still a third type of tiny bodies in the liquid part of the blood which are called **platelets.** Of these little is known.

Beside the arteries and veins there are also the **lymph vessels** in the skin, intestine, and other parts of the body which belong to the circulatory system. The liquid part of the blood in which the corpuscles float is known as **plasma.** When the blood passes into all parts of the body to nourish it, some of this plasma finds its way through the little arterial capillaries, bathing the **intercapillary** spaces. This plasma which has left the blood vessel proper to bathe the body tissues is called **lymph.** This lymph must be gathered again and made a part of the blood, so various little **lymph capillaries** drain the body and pour the lymph back into the veins. These lymphatic vessels are very delicate, and must be prepared in a special way to be seen. The little open spaces where lymph gathers and from which the lymphatics carry it to the veins are known as a **lacunae.** These lacunae also connect with larger cavities in the body.

The lymph vessels in the intestine have a special name, being called **lacteals** ( ). There are also lymphatic glands found in connection with the lymph vessels, and in the frog there are two pairs of **lymph hearts** (Figs. 11, 347) whose **contraction** propels the lymph in its circulation.

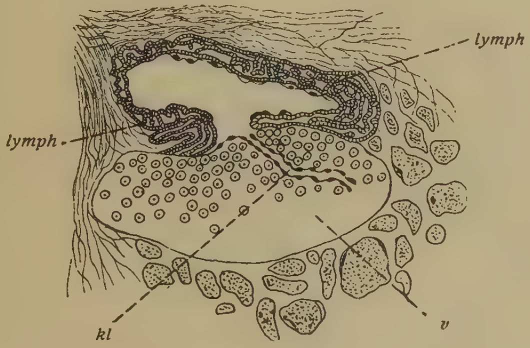


Fig. 11. Section Through a Lymph Heart. (After Weliky.)
kl—Tube-like valve at entrance of vein into the heart.
v—Vein.
lymph—Lymph-heart.

With this in mind, we take up the principal divisions of the circulatory system.

There is a **true heart** consisting, however, of only **three cavities** (Fig. 10), two thin-walled **auricles,** ( ) one on the right and one on the left side, and a muscular **ventricle.** There is also a thick-walled tube called the **truncus arteriosus** ( ) which arises from the **base** of the ventricle, and a thin-walled triangular sac, the **sinus venosus** ( ) from the dorsal side. The heart is the central pumping station of the entire circulatory system, which furthermore consists of all the **arteries, veins,** and **lymphatic structures** in the body. Arteries always carry blood **away** from the heart, veins to the heart. The **fibres** of the heart muscles run in every direction, so that in **systole,** ( ) that is, when the heart **contracts,** its size is diminished and the blood in the various cavities is forced out; then in **diastole,** ( ) when the heart again expands, the blood flows into it. The openings of both the auricles and ventricles are guarded by valves, little flaps of membrane which permit the blood to flow through the opening quite readily, but close up when the blood begins to flow backward, as it would be bound to do when the ventricle contracts, if the valves did not block the passage. The large truncus arteriosus (the proximal portion of which is called **bulbus arteriosus),** has two large branches called **aortae** ( ).

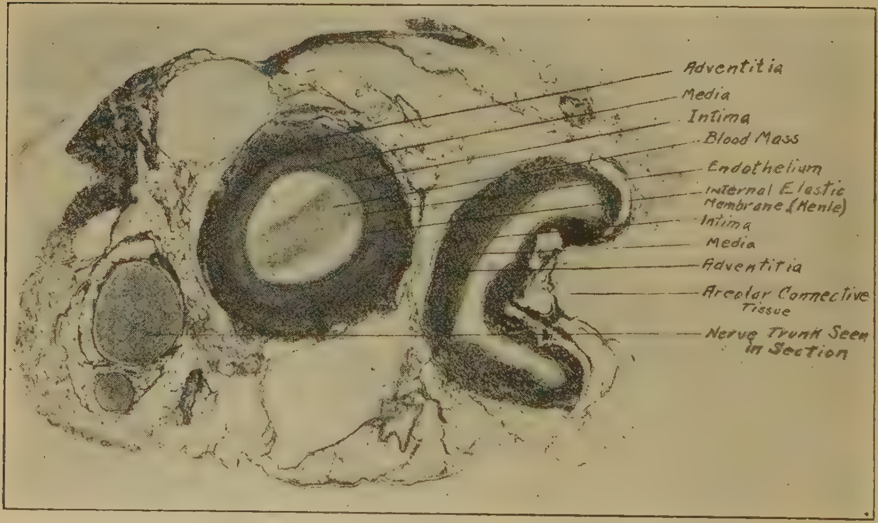

Adventitia
Media
Intima
Blood Mass
Endothelium
Internal Elastic Membrane (Henle)
Intima
Media
Adventitia
Areolar Connective Tissue
Nerve Trunk Seen in Section

Fig. 12. Femoral Nerve, Artery and Vein of Puppy.

The truncus receives the blood as it is forced out of the heart when it contracts, and from whence it is distributed to all parts of the body. The sinus venosus on the dorsal surface of the heart is the cavity into which the veins bring back the blood from all parts of the body. The sinus itself opens into the right auricle and thus receives all the blood which flows back to the heart from all parts of the body, **except the lungs.**

The blood from the lungs empties into the left auricle by two small veins, one from each lung.

Blood vessels pass to every part of the body. We know they are everywhere because one cannot insert the point of the finest needle in any part of the body without piercing them, showing they are so close together that one cannot get in between them. Arteries are always **relatively thicker-walled** and **more elastic** than veins (Fig. 12).

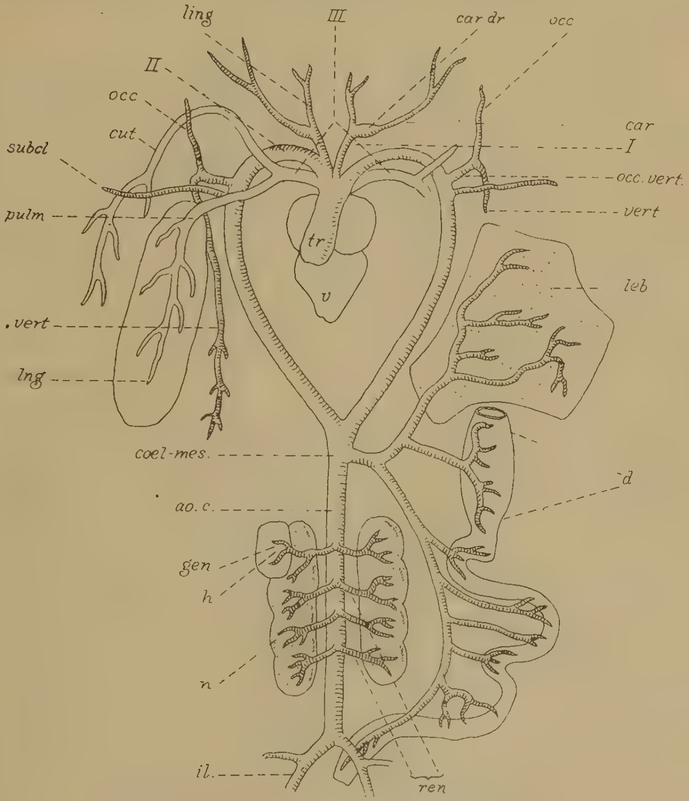


Fig. 13. The Arterial System of the Frog.

I., Carotid artery; *II.*, systemic artery; *III.*, Pulmocutaneous artery. (The three together being the aortic arches.) *ao.c.*, dorsal aorta; *car*, carotid artery; *car.dr.*, carotid gland; *coel mes.*, coeliaco-mesenteric artery; *cut.*, cutaneous artery; *d*, intestine; *gen.*, spermatic artery; *h.*, testis; *il.*, iliac artery; *leb.*, liver; *lng.*, lung; *ling.*, lingual artery; *n.*, kidney; *occ.*, occipital artery; *occ.vert.*, occipito-vertebral artery; *pulm.*, pulmonary artery; *ren.*, renal artery; *subcl.*, subclavian artery; *tr.*, truncus arteriosus; *v.*, ventricle of heart; *vert.*, vertebral artery. (After Meissner.)

The principal divisions of the arterial system (Fig. 13) may be summarized as follows:

I. The **common carotid** ( ) divides into the **lingual** or **external carotid**, supplying the tongue and neighboring parts, and the **internal carotid** which gives off the **palatine** ( ) artery to the roof of the mouth, the **cerebral carotid** to the **brain** and the

ophthalmic artery to the **eye.** There is a little swelling known as the **carotid gland** at the point where the common carotid branches.

II. The **pulmo-cutaneous** ( ) artery forms the **pulmonary** artery, passing to the lungs, and the **cutaneous** artery. The cutaneous in turn gives off the **auricularis** ( ) distributed to the lower body and neighboring parts, the **dorsalis** which supplies the skin of the back, and the **lateralis** which supplies the skin on the sides. Most of these branches also carry blood to the various respiratory organs, lungs, skin, and mouth.

III. The **systemic arches** pass outward, around the digestive canal, and then unite to form the **dorsal aorta.** Each systemic arch gives off an **occipito-vertebral artery** which divides; one branch, the **occipital,** ( ) supplying the jaws and nose; the other, again dividing forms the **vertebral,** supplying the spinal cord and muscles of the body wall, and the **subclavian** which is distributed to the shoulder, body-wall and arm. The dorsal aorta gives off the **coeliaco-mesenteric artery.** This divides, forming the **coeliac** which supplies the stomach, pancreas, and liver, and the **anterior mesenteric,** which is distributed under the intestine, the spleen, and the cloaca. Back of the **origin** of the coeliaco-mesenteric, the dorsal aorta gives off four to six **urinogenital arteries** which supply the kidneys, reproductive organs, and fat bodies. A small **posterior mesenteric artery** arises near the posterior end of the dorsal aorta passing into the rectum. In the female this artery also supplies the **uterus.** The dorsal finally divides into two **common iliac** ( ) **arteries** which are distributed into the ventral body-wall, the rectum, bladder, the anterior part of the thigh (here called **femoral artery**), and other parts of the hind limbs **(sciatic artery).**

All the arteries finally break up into a vast number of microscopic thin-walled vessels called capillaries (Lat. capillus=hair) by which every part of the body is reached.

THE VEINS

The veins (Fig. 14) return the blood to the heart by **draining** all parts through venous capillaries; the veins reversing the arterial system by constantly becoming larger and larger. It will be noted here that the blood vessels thus form a **closed system** and the blood that leaves the heart returns without leaving the vessels. "The blood from the lungs is collected in the pulmonary veins and poured into the **left** auricle. The rest of the venous blood is carried to the **sinus venosus** by three large trunks, the two **anterior venae cavae** ( ) and the **posterior vena cava.** The anterior venae cavae receive blood from the **external jugulars** ( ) which collect blood from the tongue, thyroid, and neighboring parts, the **innominates** which collect blood from the head by means of the **internal jugulars** and from the shoulder by means of the **subscapulars,** and the **subclavians** which collect blood from the fore limbs by means of the **brachial**, and from the side of the body and head by means of the **musculocutaneous veins.** The posterior vena cava receives blood from the liver by means of two **hepatic**

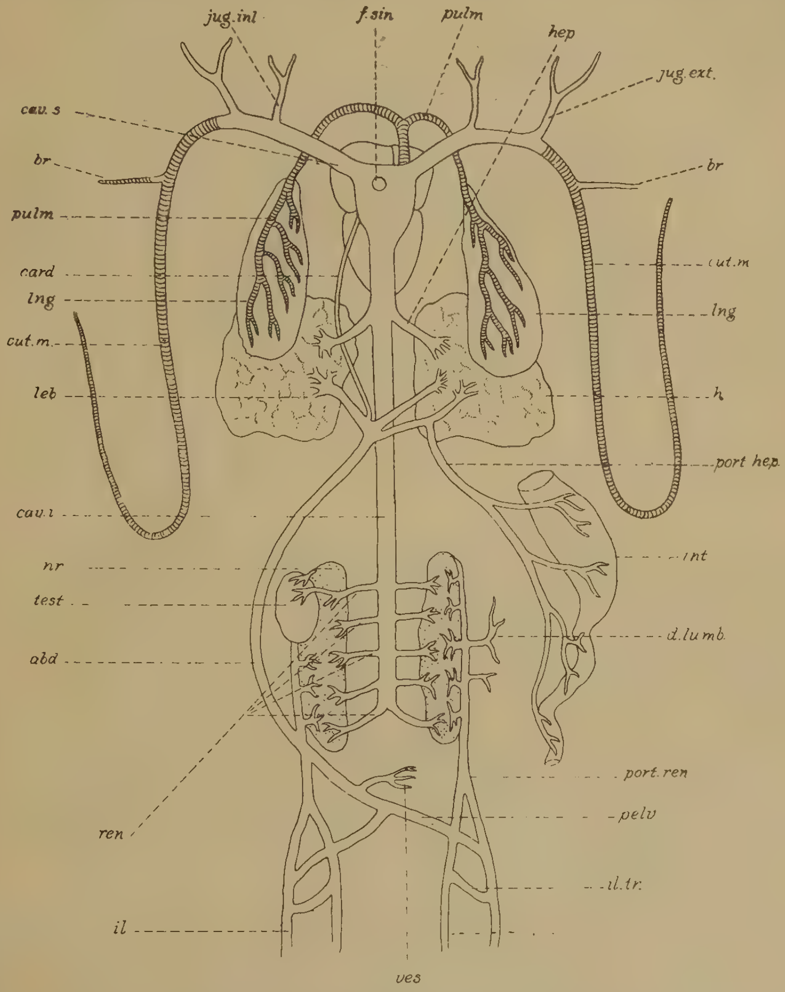


Fig. 14. The Venous System of the Frog.

abd., Abdominal vein; *br.*, brachial vein; *card.*, cardiac vein; *cav.i.*, post caval vein; *cav.s.*, precaval vein; *cut.m.*, musculo-cutaneous vein; *d.*, intestine; *d.*, *lumb.*, dorso-lumbar veins; *f.sin.*, opening between sinus venosus and auricle; *h*, liver; *hep.*, hepatic vein; *il.*, iliac or femoral vein; *il.tr.*, transverse iliac vein; *leb.*, liver; *lng.*, lung; *nr.*, kidney; *pelv.*, pelvic vein; *port.hep.*, hepatic portal vein; *port.ren.*, renal portal vein; *pulm.*, pulmonary vein; *ren.*, renal vein; *sc.*, sciatic vein; *test.*, testis; *ves.*, vesicle veins. (After Meissner.)

veins, from the kidneys by means of four to six pairs of **renal veins,** and from the reproductive organs by means of **spermatic or ovarian veins.**

"The veins which carry blood to the kidneys constitute the **renal-portal** ( ) system. The renal-portal vein receives the blood from the hind legs by means of the **sciatic** and **femoral veins,** and blood from the body wall by means of the **dorso-lumbar vein.**

"The liver receives blood from the **hepatic-portal system.** The femoral veins from the hind limbs divide, and their branches unite to form the **abdominal vein.** The abdominal vein also collects blood from the bladder, ventral body wall, and heart. The **portal vein** carries blood into the liver from the stomach, intestine, spleen, and pancreas."

"The sinus venosus contracts first, forcing the impure venous blood into the **right auricle**; then both auricles contract and the **oxygenated** ( ) **blood** brought to the **left auricle** by the pulmonary veins is forced into the **left part of the ventricle,** while the **impure blood** from the right auricle is forced into the **right side of the ventricle.** The ventricle then contracts and the impure blood is forced out, first passing principally into the pulmocutaneous arteries and thence to the lungs and skin, and the oxygenated blood is pushed out later through the carotid and systemic arteries to the other parts of the body." The blood then passes through the various blood vessels which become smaller and smaller. These minute vessels are called capillaries. It is here that the food and the oxygen of the blood **bathe the tissues,** and **waste products** are taken up.

The renal-portal system carries the blood from the legs and posterior portions of the body to the kidneys where **urea** and similar impurities are taken out. The hepatic-portal system carries **all** the blood **from the digestive tract** into the liver where bile and glycogen are formed. All blood brought to the lungs and skin is oxygenated and carried back to the heart.

The liquid in which the **blood corpuscles** float is called **blood plasma** as long as it is contained **within the walls** of the blood vessel. When it leaves the blood vessel and bathes various parts of the intervening spaces, it is called **lymph**; **while,** if it should be taken **out of the body entirely,** it would be called **serum.**

The lymph spaces in the frog's body are very large and communicate with one another as well as with the veins. There are four so-called **lymph-hearts** (Figs. 11, 347); two near the third **vertebra,** and two near the end of the vertebral column. These **lymph-hearts** force the lymph into the **internal jugular** and **transverse iliac veins** by their pulsation. The lymph itself is colorless, and whatever corpuscles it may contain are likewise colorless.

RESPIRATION

As has already been mentioned, breathing takes place through the **skin,** both in water and air, although the lungs are naturally the principal organs of respiration. The air is taken in through the external nares into the **olfactory** ( ) chamber, then through the internal or posterior nares into the mouth cavity. The valves, which have already been mentioned, then close; the floor of the mouth is raised, the air being forced through the **larynx** (   ) to the lungs themselves. The contraction of the body-wall forces the air back from the lungs into the mouth. It is interesting to note that the glottis closes, while the floor of the mouth alternately raises and lowers—thus drawing in and expelling air through the nares into the mouth cavity by what are called throat movements.

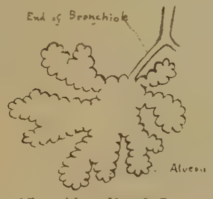


Fig. 15. Alveoli of Lungs.

The lungs themselves (Fig. 15) are formed of minute chambers called **alveoli** (   ) the walls of which are filled with little blood capillaries. The larynx is strengthened by five **cartilages,** (   ) across which the vocal cords are stretched. The expulsion of air from the lungs across the free ends of the vocal cords produces the sound known as **croaking.** The **laryngeal muscles** regulate the **tension** of the cords, causing the particular pitch of the sound made.

Male frogs often have a pair of vocal sacs opening into the mouth cavity, serving as **resonators** (   ) and increasing the volume of the sound.

THE EXCRETORY SYSTEM

The food taken into the body is said to be **ingested.** The part of the food which is actually taken into the blood as nutriment is said to be **digested,** and that part of the food which passes directly through the body without becoming a part of it is said to be **egested.** Every living cell ingests and must **assimilate** food in order to live; consequently, it must also get rid of that material which has already served a **nutrient purpose,** and this getting rid of a substance that has been digested and that has served a purpose is called **excretion.** This word must not be confused with **secretion,** which means that a substance is given off from the cell or gland which is to be used again by some part of the body. The waste matter that is eliminated from the body in the form of **carbon dioxide** is thrown off through the organs of respiration, but the solid products have specialized organs for their removal. The skin serves as such an organ to a small extent. The frog does not use the skin in this way anywhere nearly to the extent that human beings do, because the **amphibia** do not possess **sweat glands.** The liver and the walls of the intestine are also excretory in character.

The most important organs for excretory purposes, however, are the kidneys, two oval, flattened dark red bodies lying **behind the peritoneum** in the dorsal portion of the body-cavity. It is well to know that the kidneys are about the only abdominal organs, even in the higher forms, that lie **between the dorsal peritoneum and body-wall.** The kidneys are abundantly supplied with blood vessels, though they, themselves, are composed of connective tissue. The fact that so many blood vessels run to them shows that they are decidedly important organs. Each kidney contains a great number of coiled tubes called **uriniferous tubules,** each one of which begins in a **Malpighian body** near the ventral surface (Fig. 16). This body consists of a **knot of blood vessels** called the **glomerulus** and a surrounding membrane known as **Bowman's capsule.** This capsule is really the thinned out and expanded end of a uriniferous tubule which has become pushed in by the glomerulus. All excretions are carried by the uriniferous tubules to a **collecting tubule,** and thence to the **ureter.** The ureter of each kidney passes **caudad** (   ) toward the cloaca, emptying therein, thence into the bladder, a large two-lobed sac. This latter organ may be collapsed if empty, or, if filled with the urine secreted by the kidney, may be considerably distended. The ventral surface of the kidney has a great many **ciliated** (   ) **funnels** called **nephrostomes** (Fig. 168) whose expanded ends open into the coelom. In the young frog these are connected with the **renal tubules,** while in the adult they open into branches of the **renal vein.** The **renal arteries** and the **renal-portal vein** carry the blood to the kidney, leaving again by the renal veins. The glomeruli are supplied only with arterial blood, but the renal tubules receive blood from the renal portal veins and to a slight extent from the renal arteries.

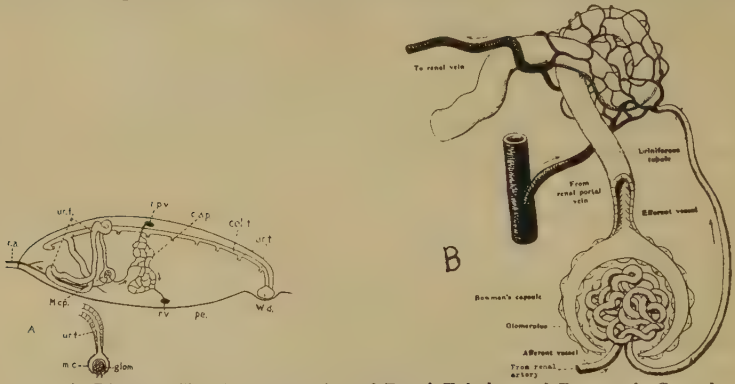


Fig. 16. A, Diagram Showing Formation of Renal Tubules and Bowman's Capsule. (After Borradaile.)

cap., Capillary plexus, *col.t*, collecting tubule; *mc.* and *M cp.*, Bowman's capsule (Malphighian capsule); *r.a.*, renal artery; *r.v.*, renal vein; *r.p.v.*, renal portal vein; *ur.t.*, uriniferous tubules; *w.d.*, Wolffian duct.

B. Diagram Showing Relation of Glomerulus and Renal Tubules to the Blood Vessels. (After Guyer.)

The **functions** of the kidney, as already stated, is the **elimination** of waste matter from the blood. The excretion itself, known as urine, is composed of a large number of compounds in solution. Most of the **nitrogen** leaves the body in the form of **urea** $(NH_2)2CO$, a white, crystalline compound, very soluble in water.

It is interesting to remember that this was the first **organic** chemical compound actually manufactured in the laboratory.

Urea represents the final product of the breaking down of the nitrogenous substances of the body, and it has been shown that the formation of this substance takes place to a large extent in the liver from which it is given to the blood by a process of internal secretion. Beside urea, urine contains various salts in solution such as chlorides, sulphates, phosphates of sodium, potassium, calcium, and magnesium, as well as other substances.

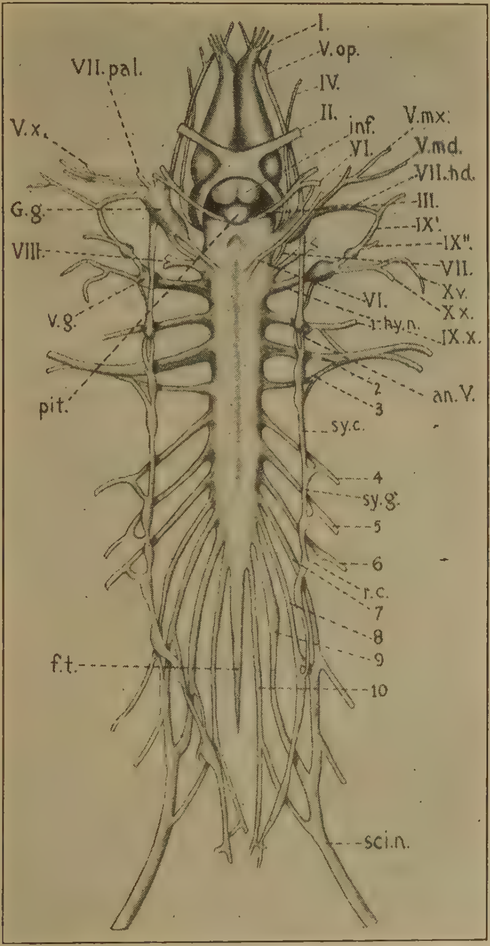


Fig. 17. The Central Nervous System and Principal Nerves of a Frog, Seen From Below.

I., Olfactory lobes; *II.*, Optic chiasma; *I.-X.*, cranial nerves; 1-10, spinal nerves; *V.md.*, *V.mx.*, *V.op.*, mandibular, maxillary, and opthalmic branches of fifth cranial nerve; *VI'*, sixth cranial nerve after leaving the Gasserian ganglion; *VII.hd.*, *VII-pal.*, hyoidean and palatine branches of seventh cranial nerve; *IX'.*, branch from ninth cranial nerve to seventh; *IX".*, main branch of ninth cranial nerve; *X.v.*, tenth cranial nerve passing to viscera; *V.x.*, a small twig from the undivided main branch of the fifth cranial nerve; *X.x*, a branch from the vagus to certain muscles; *an.V.*, annulus of Vieussens through which the subclavian artery passes; *f.t.*, filum terminale; *G.g.*, Gasserian ganglion; *hy.n.*, hypoglossal (first spinal) nerve; *inf.*, infundibulum; *pit.*, pituitary body; *r.c.*, ramus communicans; *sci.n.*, sciatic nerve; *sy.c.*, longitudinal commissure of sympathetic chain; *sy.g.*, sympathetic ganglion; *v.g.*, vagus ganglion. (Redrawn from Borradaile.)
Compare with Figures 472C, 478, 480, 483.

As far as we know at this moment, practically all of the excreted substances of the kidney pass through the glomeruli. The exact function of the glomeruli are not known, though there are many theories regarding it.

The bladder arises as an **outpushing** of the ventral wall of the cloaca. It is regarded as **homologous** ( ) with the **allantois** (Fig. 363) of the embryo of higher vertebrates. It is very **distensible.** There are **circular muscles** at the mouth of the bladder which are able to contract and expand, the contraction closing the cloacal opening to make it possible for urine to collect in the bladder.

THE NERVOUS SYSTEM

One of the necessary conditions of life is what is commonly called **irritability,** which means that the organism can, when properly stimulated, perform certain movements. In the higher forms of animals a definite nervous system does this work and permits a **co-ordination** of activities in different parts of the body. For example: In order to leap when danger threatens, the frog must be able to send the necessary nervous impulses to both hind legs at one time, for if only one leg should get an impulse, the frog would fall over on one side instead of propelling his body for some distance ahead.

There is also another function the nervous system has to perform, and that is the **accumulation** of the **effects of experiences** which the animal in question has had, so that such animal may profit by the memory of these experiences in new situations. When this ability is highly developed, we speak of it as **reasoning** or **intelligence,** whereas when the animal **only remembers,** let us say, a physical punishment for having performed a given act, and by sheer association of the punishment and the act ceases to perform the act which brought about the punishment, such an association is not known as intelligence, but as **association memory.**

Practically all parts of the body have nerves running to them. There are three closely associated divisions in the nervous system (Fig. 17) known as:

1. The **central,** consisting of brain and spinal cord.
2. The **peripheral,** consisting of cerebral and spinal nerves, and
3. The **sympathetic,** supplying non-striated muscles.

THE CENTRAL NERVOUS SYSTEM

As in all of the vertebrates, the brain and spinal cord are on the **dorsal side** of the animal, being contained within a bony case known as the **skull** and **neural canal.** It will be noted that beginning at the anterior end, the brain consists of quite distinct parts, namely, the **olfactory lobes,** the **cerebral hemispheres,** the two large **optic lobes,** a well developed **mid brain,** a small **cerebellum,** and a broadening of the spinal cord itself called the **medulla oblongata.** From the ventral surface, we may see in addition the crossing from one side to the other of the **optic nerves,** known as the **optic chiasma.**

A small process directly behind the optic chiasma called the **infundibulum** (   ) ends in another small body, the **pituitary body** (   ) or **hypophysis** (   ).

On the dorsal side of the mid brain is found the **pineal gland** (   ) or **epiphysis** (   ), already mentioned as a rudimentary organ which, in some forms of the reptiles, forms a **dorsal median eye.** The **cerebrum** and **optic lobes (thalamencephalon)** (   ) together constitute the **fore brain,** the **optic lobes form the mid brain,** the **cerebellum** and **medulla** form the **hind brain.**

It is not clear what functions each part of the frog's brain can perform. From various experiments, however, it is known that the frog loses the power of **spontaneous movement** if the mid brain and cerebral hemispheres are removed, while the spinal cord becomes very irritable if the optic lobes are cut away. No function has yet been definitely ascribed to the cerebellum and even when all of the brain, with the exception of the medulla, is removed, the animal "breathes normally, snaps at and swallows food, leaps and swims regularly, and is able to right itself when thrown on its back." If the posterior portion of the medulla is removed, the frog dies.

THE SPINAL CORD

The spinal cord passes down through the bony **vertebral** or **spinal column.** It is short and somewhat flattened. There is an enlargement in the **brachial** region where the nerves pass off to the fore limbs, and one further back where the large nerves originate which supply the hind legs. The cord tapers to a narrow thread called the **filum terminale** which extends into the **urostyle.** There is a **median fissure** on both dorsal and ventral sides of the cord, while from the sides of it, the roots of the spinal nerves are given off. The cord itself is surrounded by two membranes, an outer, the **dura mater,** and an inner known as the **pia mater.** There is an H-shaped **central mass of gray matter** consisting of nerve cells, and an **outer mass** of **white matter** composed of nerve **fibers.**

There is a little opening through the center of the cord called the **central canal.** The various cavities in the brain are a continuation and expansion of this central canal.

THE PERIPHERAL NERVOUS SYSTEM

There are **ten pairs** of **spinal nerves** in the frog, each arising by a dorsal and ventral **root** and springing from the **horns** of the gray matter of the cord (Fig. 470). The two roots unite to form a **trunk,** passing out between the **arches** of the vertebrae.

The **brachial,** or arm branches, are made up of the **second,** as well as branches from the **first** and **third pairs** of spinal nerves, and pass to the fore limbs and shoulder, while the **sciatics** arise from **plexuses** composed of the **seventh, eighth,** and **ninth** spinal nerves, and run to the legs.

There are also **ten pairs** of **cranial nerves** which supply the **organs of special sense,** certain muscles, various organs of the head, the heart, lungs, and stomach. They are named as follows:*

---

*There are two additional cranial nerves in the higher animals, the spinal accessory and hypoglossal, and medical students remember them by the following verse, the first letter of each word being the initial letter of the correspondingly numbered nerve:

I. On
II. Old
III. Olympus
IV. Towering
V. Tops
VI. A
VII. Finn
VIII. And
IX. German
X. Picked
XI. Some
XII. Hops

1. The **olfactory** ( ), nerves running from the olfactory lobes to the nasal cavities.

2. The **optic** nerves, running from the optic lobes, **crossing each other** to form the **optic chiasma** and passing to the eye on the opposite side of the head.

3. **Oculomotor,** supplying the muscles of the eye.

4. **Trochlearis** ( ), sometimes called the **patheticus,** supplying the muscles of the eye.

5. The **Trigeminus** ( ), or **trifacial,** a sensory nerve, supplying the sides of the head.

6. The **Abducens** ( ), supplying the muscles of the eye.

7. **Facial,** chiefly motor in its action and supplying the sides of the head.

8. **Auditory,** supplying the inner ear.

9. **Glossopharyngeal** ( ), a sensory nerve, supplying the pharynx and tongue.

10. **Pneumogastric** ( ), or **vagus,** supplying the larynx, heart, and stomach.

THE SYMPATHETIC SYSTEM

The main trunks of this system consist of a nervous strand on each side of the spinal column (Fig. 337). Throughout the abdominal cavity one may see the chain of minute **nerve ganglia, ten** in number, which are also connected with the spinal nerves. From these chains of ganglia tiny nerves are given off, supplying the intestine, the kidney, and other abdominal organs.

Although the sympathetic system is connected with the spinal nerves, it has entirely distinct and separate functions. **Microscopically,** one finds quantities of **neurones,** each with its little **cell-body, dendrites** ( ) and **axon.** These are massed in the brain and cord, as well as in the ganglia outside of the cord. Some of them carry **impulses to the center** and some **away** from it. There are several branches where a vast intermingling of the sympathetic strands is seen, the principal ones being called the **coeliac** ( ) or **solar plexus,** supplying the stomach, intestine, liver, pancreas, spleen, and sending fibers to the gonads and kidneys, and the **urogenital plexus,** supplying kidneys and gonads primarily.

THE SENSE ORGANS

If one marks a series of spaces on the **volar** ( ) surface of the fore arm of a human being about a millimeter square, and such person is then blindfolded, it will be found that when a cold needle touches certain squares he will feel a sensation of cold, whereas if it touches certain other squares, he will feel a sensation of heat. From this experiment it is learned that a great many, if not all, nerves have a very special and definite work to perform.

Where a great mass of such specialized nerve endings is grouped in one place, it produces an organ of **special sense** such as the **eye**, the **ear**, the **nose**, the **tongue**. All of these organs are groups of nerves whose endings are on the **surface** of some part of the body, and carry sensations **inward to** the **central nervous system**. These are called **sensory** nerves.

The nerves which **begin in the central nervous system** and go **outward** to some of the muscles, producing various movements of those muscles, are called **motor** nerves.

Both sensory and motor cells may unite in a **ganglion** and have both types of fibers run in the same sheath from there on; these are called **mixed** nerves.

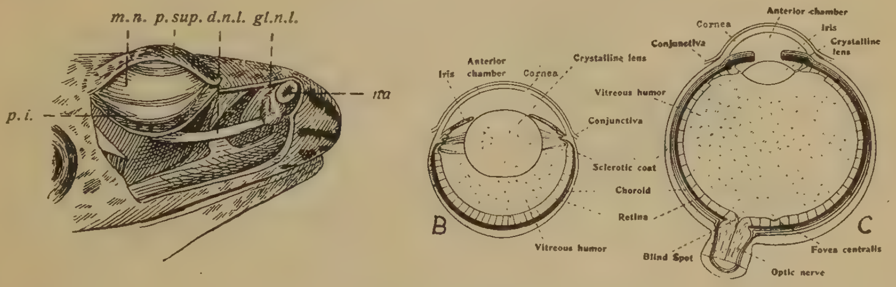


Fig. 18. The Eye.

A. Eye in position. *d.n.l.*, lachrimal duct leading from eye to interior of nose; *gl.n.l.*, lachrimal gland; *m.n.*, nictitating membrane; *na.*, nares; *p.i.*, lower eye-lid; *p.sup.*, upper eye-lid. (After Schimkewitsch.)

B. Diagrammatic section through the optical axis of the eye of the frog.

C. Diagrammatic horizontal section of the eye of man. (After Guyer.)

THE EYE

Probably the most important special sense organ is the eye (Fig. 18). Practically only one type of sensation is carried by the nerves of this special sense organ, and that is light perception. The eye of the frog is a large spherical organ similar to the eye of all of the higher animals. The walls of the organ are opaque, with the exception of a transparent portion directly in the foreground occupying about one-third of the eye ball and called the **cornea** ( ).

The darker portion of the eye acts as does the dark chamber of a camera. This chamber takes up about two-thirds of the posterior part of the eyeball and consists of three layers. Toward the exterior is found the **sclerotic** (   ) coat made up of **fibrous tissue** and **cartilage.** Then follows a thin **pigment-containing** coat, known as the **choroid** (   ) and in the inside of this a very thin layer, known as the **retina** (   ). It is the retina which is sensitive to light. Almost in the center, but a little to one side of the back chamber, the **optic nerve** enters, spreading out on the retina, so that it has a considerable area that light may affect. The **chamber** of the eye itself is divided in two parts by a transparent spherical, **crystalline** lens which is held in position by several bands of fibers. The lens is partly covered anteriorly by an opaque membrane, in reality a continuation of the choroid, growing out of the wall of the chamber on all sides. This membrane is known as the **iris** (   ), and it covers the entire outer portion of the lens with the exception of the center. This central uncovered portion is called the **pupil,** and it is through this the light enters. There are pigment cells in the iris which give the color to the eye.

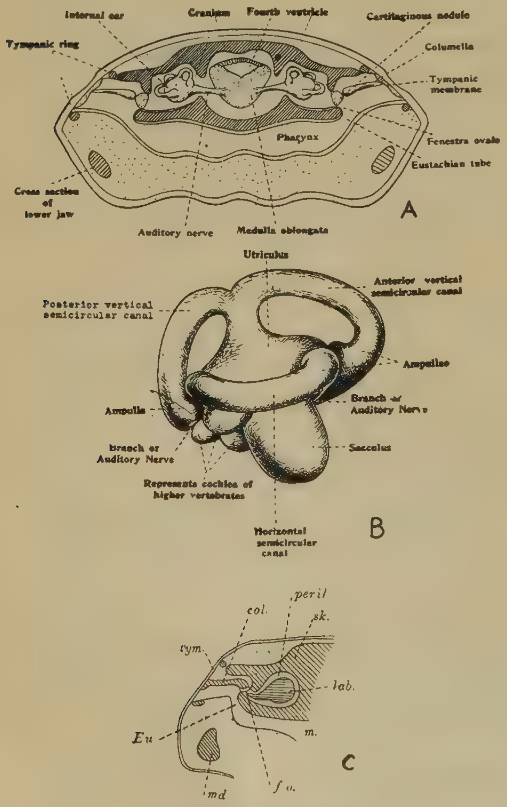


Fig. 19. The Ear.

A. Diagrammatic transverse section of the head of the toad showing arrangement of the parts of the ear. (After Guyer from Jammes.)

B. The labyrinth of the right ear of the frog, seen from the outer side.

C. A diagram of the ear of the frog. *col.*, Columella; *f.o.*, fenestra ovalis; *Eu.*, Eustachian tube; *lab.*, part of the membranous labyrinth, containing endolymph; *m.*, mouth; *md.*, mandible; *peril.*, perilymph; *sk.*, skull; *tym.*, tympanic membrane. (B and C, from Borradaile.)

Both of the eye-chambers are filled with a transparent liquid. That between the cornea and the lens is called the **aqueous humor** (   ) and that back of the lens, which is quite thick, is called the **vitreous humor** (   ). The retina itself is quite complicated, being composed of thousands of **end organs** of sensory nerves, highly sensitive to the light which is focused upon it by the lens. There are six muscles attached to the eyeball by means of which it can be moved in practically any direction (Fig. 466).

THE EAR

As has already been noted, there are really no external ears on the frog though there is a rounded, flat membrane covering the real ear (Fig. 19). Directly beneath this outer membrane there is another tougher one which is known as the **tympanic membrane** ( ). It extends over a shallow, cone-shaped cavity called the **tympanum,** or **ear-drum,** and connects with the mouth through the **Eustachian tube** ( ).

The **columella** ( ), a slender bar of bone and cartilage, extends across this, being attached to the membrane at one end and connected with the **inner ear** at the other. It is by this little bar that vibrations of the outer membrane are carried to the inner ear. This inner ear is the real organ of hearing and is made up of the **sensory end** of the **auditory nerve.** The auditory nerve lies embedded within the skull itself.

There are several **semi-circular canals** present which function as a balancing organ so that the animal can keep an upright position. These form what are often called an "organ of the **sense of equilibrium.**"

THE OLFACTORY ORGAN

There is little known regarding what effect the sense of smell has in the life of a frog, but it is known that there are little **olfactory sacs** just within the bones into which the openings from the nostrils lead. The air enters these and then passes through the bones into the mouth by the **internal nares.** The ending of the olfactory nerve is in this little sac, where it is spread out to a considerable extent and where vapors of various kinds in the air may affect it.

THE TONGUE

The sense of taste probably resides in the tongue, though there are various small structures on the roof and floor of the mouth which may have similar functions.

Conclusions of this kind are based on observations of what the frog does when different tasting liquids are brought in contact with the structures mentioned.

The fact that the animal does react differently to different tastes is again accounted for by the finding of nerve endings in these supposed taste organs.

TOUCH AND PRESSURE

These senses are located in the skin in various parts of the body. This is due to the fact that there are many sensory nerves whose end-organs terminate in the skin. Just as the experiment of the cold needle

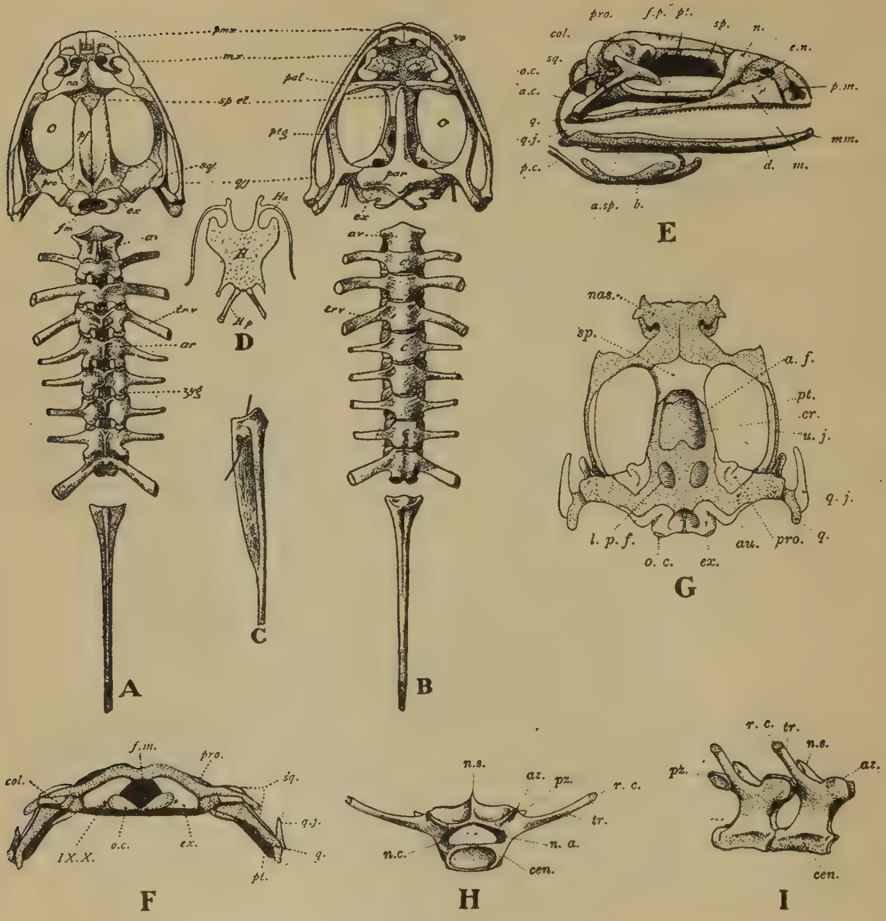


Fig. 20. The Axial Skeleton of the Frog.

A. The skull and vertebral column of frog viewed from dorsal surface.
B. The same from the ventral surface.
C. Lateral view of the urostyle; a bristle is passed through the foramen for the tenth spinal nerve.
D. The branchial skeleton of the frog: *O.*, orbital fossa; *pmx.*, premaxilla; *mx.*, maxilla; *q-j.*, quadrato-jugal; *na.*, nasal; *pf.*, parieto-frontal; *ex.*, exoccipital; *fm.*, foramen magnum; *pro.*, pro-otic; *sq.*, squamosal; *sp.et.*, sphenethmoid; *par.*, parasphenoid; *pal.*, palatine; *vo.*, vomer; *ptg.*, pterygoid; *av.*, atlas; *c.*, centrum; *ar.*, neural arch; *zyg.*, zygapophysis; *trv.*, transverse process; *ur.*, urostyle; *H.*, body of hyoid; *Ha.*, anterior cornu; *H.p.*, posterior cornu of hyoid.
E. The skull of a frog, seen from the right side: *a.c.*, Anterior cornu of hyoid; *a.sp.*, angulo-splenial; *b.*, body of hyoid; *col.*, columella; *d.*, dentary; *e.n.*, external nasal opening; *f.p.*, fronto-parietal; *m.*, maxilla; *mm.*, mentomeckelian; *n.*, nasal; *o.c.*, occipital condyle; *p.c.*, posterior cornu of hyoid; *p.m.*, premaxilla; *pro.*, prootic; *pt.*, pterygoid; *q.*, quadrate; *q.j.*, quadratojugal; *sp.*, sphenethmoid; *sq.*, squamosal.
F. The skull of a frog seen from behind: *col.*, Columella; *ex.*, exoccipital; *f.m.*, foramen magnum; *o.c.*, occipital condyle; *pro.*, prootic; *pt.*, pterygoid; *q.*, quadrate; *q.j.*, quadratojugal; *sq.*, squamosal; *IX.X.*, foramen for ninth and tenth cranial nerves.
G. The cartilaginous skull of a frog, seen from above after the removal of most of the bones: *a.f.*, Anterior fontanelle; *au.*, auditory capsule; *cr.*, cranium; *ex.*, exoccipital; *l.p.f.*, left posterior fontanelle; *nas.*, nasal capsule; *o.c.*, occipital condyle; *pro.*, prootic; *pt.*, pterygoid; *q.*, quadrate; *q.j.*, quadratojugal; *sp.*, sphenethmoid; *u.j.*, upper jaw bar.

has demonstrated particular sensations for particular nerve endings in the arm of man, so it may be supposed that these different end-organs in the skin may have similar definite functions.

THE SKELETON

The frog is possessed of an **endoskeleton** as is man. The bones and cartilages constituting this endoskeleton furnish a support, holding in position all the muscles and organs of the body.

For convenience's sake the skeleton is divided into two parts, the **axial** portion (Fig. 20), comprising skull and vertebral column, and the **appendicular** portion (Figs. 21, 22), consisting of the **pectoral** or shoulder, and **pelvic** or hip girdles, together with the bones of the limbs which these girdles support.

The frog's skeleton possesses about ninety **articulated** bones (united at the joints). The **skull** has the various bones comprising it so firmly fused that they appear as a single bone. Even the seemingly single bone of the fore arm will be found to consist of two bones which have also fused together.

THE AXIAL SKELETON

This is divided into the **skull** [cranium ( ) and **visceral skeleton** ( )], and **vertebral column.** The two divisions of the skull mentioned above are made up of the **brain case** together with the **auditory** ( ) and **olfactory capsules** ( ) which constitute the **cranium.** The jaws and **hyoid arch** ( ) together, form the **visceral skeleton.**

The inside of the cranium where the brain is placed is known as the **cranial cavity.** The skull itself is composed of thirty-two bones and cartilages fused together so as to appear almost a solid structure. The cranial bones form the **roof, walls,** and **floor** of the cranial cavity.

The **floor** is composed of the **basioccipital** ( ) and the **parasphenoid** ( ).

The **walls** consist of the **parietals** ( ), the **otic bones** ( ), and the **exoccipital** ( ).

The roof is made up of the **supraoccipital** ( ) and the **frontals.**

The **facial** bones, forming the face, consist of **nasals** ( ), the **premaxillas** ( ), and the **maxillas** ( ) above, and **vomers** ( ) below. The premaxillas and the maxillas, however, are a part of the visceral skeleton comprising, together with a pair of **quadrangulars,** the upper jaws.

H and I. Vertebræ of a frog. H, fourth vertebra, seen from in front; I, sixth and seventh vertebræ from the right. *az.*, Prezygapophysis; *cen.*, centrum; *n.a.*, neural arch; *n.c.*, vertebral foramen; *n.s.*, neural spine; *pz.*, postzygapophysis; *r.c.*, cartilage at end of transverse process; *tr.*, transverse process.
(A, B, C and D from Bourne, after Ecker. E, F, G, H and I, after Borradaile.)

The maxilla and the premaxilla bear teeth. The lower jaw or **mandibular arch** ( ), is made up of a pair of cartilaginous rods (Meckel's cartilages), enforced by a pair of **dentary bones** ( ) and a pair of **angulo-splenials** ( ). The jaws themselves are attached to the cranium by an apparatus consisting of **squamosals** ( ), **pterygoids** ( ) and **palatines** ( ), the whole often known as a **suspensory apparatus,** or a **suspensorium** ( ). These bones, though attached to the cranium in the adult frog, are at first free from it, being in reality the upper parts of what are called **visceral arches,** which lie below the cranium. The **second arch** is called the **hyoid,** and is quite **rudimentary,** only a small part of it being left in the adult frog. In the higher forms such as man, this is a well-developed V-shaped arch to which the tongue is attached, but in the frog it remains only as a flat plate, partly bone and partly cartilage, so loosely attached to the skull that it is quite easily, and one might add, usually, lost. It lies directly beneath the **larynx** ( ) in the frog, giving this support and rigidity, being connected with the skull by **ligaments** ( ) only.

In the young frog all parts of the skull are soft, but true bone forms as development goes on. A part of the skull forms originally as cartilage, a material that is harder than membrane but softer than bone. Mineral matter is deposited a little later in the cartilage, causing **ossification** ( ) or true manufacture of bone.

Bones such as the occipitals, parietals, pterygoids, and the mandibles, formed from cartilage, are known as **cartilaginous bones,** the other ones being manufactured first as membranes. Here, too, mineral matter is laid down and the structures become hardened. Such bones as frontals, parietals, parasphenoids, squamosals, nasals, vomers, premaxillas, and maxilla are of the latter kind and are called **membrane bones.** The projections at the posterior end of the skull where it connects with the vertebral column are called **occipital condyles** ( ); and the large opening directly between these through which the spinal cord continues down through the bony canal of the spinal column is called the **foramen magnum** ( ).

THE VERTEBRAL COLUMN

This consists of nine separate segments of bone (H and I, Fig. 20), each known as a vertebra ( ), and a long platelike posterior extension, the **urostyle** ( ). Each vertebra consists of a **centrum** and a neural arch ( ), the latter enclosing the **neural foramen**; on each side of all but the first vertebra is found a **transverse process,** while all vertebrae possess a **dorsal spine** and a pair of smooth surfaces where each successive vertebra rests upon the next following. These **articulating processes** are called

zygapophyses ( ). The little bones themselves are held together by ligaments and move on one another by means of the centrum and zygapophyses. This permits a firm **axial support**, while also allowing for the bending of the body. By having all the vertebrae, one immediately above the other, the neural opening is continuous, so that the spinal cord not only lies free, but the vertebrae themselves are thus prevented from bending sufficiently to damage the cord.

The surfaces of the centra unite by a **ball and socket joint.** Each of the first seven vertebrae possesses a ball on the posterior and a socket on the anterior surface. The eighth, however, is concave on both surfaces and the ninth is convex on both. It is important to know the difference in action that this entails. Although all nine vertebrae are much alike, they can easily be distinguished from each other. The first possesses no transverse process, while the centrum of the ninth has two convex posterior surfaces and very large transverse processes. It is from this last vertebra that the urostyle, the long slender bone, extends backward to the end of the body.

The urostyle is supposed to represent the tail found in allied animals, such as the **salamanders.** The spinal cord actually extends into the urostyle, but passes out almost immediately through two small openings on either side, as two rather tiny **filaments.**

There are no ribs in the frog, and the transverse processes end rather abruptly a very short distance from the centrum.

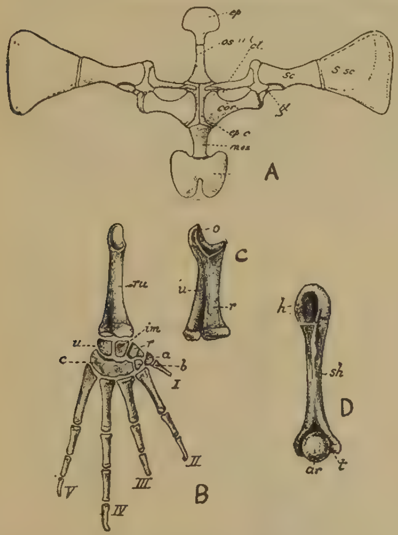


Fig. 21.

Pectoral Girdle, Arm, and Hand, of Frog.
A. The shoulder girdle of the frog; the scapula and suprascapula are turned outwards. *ep.*, episternum; *os.*, omosternum; *ep.c.*, epicoracoids; *mes.*, mesosternum; *xi.*, xiphisternum; *s.sc.*, suprascapula; *sc.*, scapula; *gl.*, glenoid cavity; *cor.*, coracoid; *cl.*, clavicle.
B. Forearm and hand of right side, as seen from above: *ru.*, radio-ulna; *I—V.*, the five digits; *r.*, radiale; *im.*, intermedium; *u.*, ulnare; *a.*, first distal carpal bone; *b.*, second distal; *c.*, third distal.
C. Radio-ulna of right side: *o.*, olecranon; *r.*, radius; *u.*, ulna.
D. Humerus: *h.*, head; *sh.*, shaft; *ar.*, distal articular knob; *t.*, trochlea. (From Bourne, after Ecker.)

THE APPENDICULAR SKELETON

The shoulder or **pectoral girdle** ( ) (Fig. 21) serves as an attachment for the muscles that move the fore limbs, and also as a protection for the organs in the anterior portion of the trunk.

The girdle itself surrounds the body just back of the head, consisting of a paired **scapula** ( ), the dorsal part of which is made of cartilage, a **coracoid** ( ), a **precoracoid** or **epicoracoid,** and a **clavicle** ( ) fused together. At the meeting of coracoid and scapula there is a little smooth cavity where the fore arm joins the girdle called the **glenoid fossa** ( ). Where coracoid and clavicle meet at the mid line on the ventral side of the body, there are four bones. These four actually are a part of the axial skeleton, but are usually classified as a part of the appendicular as well. The most anterior one of the bones is called the **episternum,** the one between this and the clavicle is the **omosternum,** while the posterior one closest to the omosternum is the **mesosternum,** and the one projecting farthest backward is the **xiphisternum.**

The fore limbs are made up of a long bone, the **humerus** ( ), joining the pectoral girdle in the glenoid fossa at its **proximal end** ( ) and with the **radio-ulna** at the **distal end** ( ). This latter bone constitutes the skeleton of the fore arm and in reality consists of two bones, the radius and the ulna, fused together.

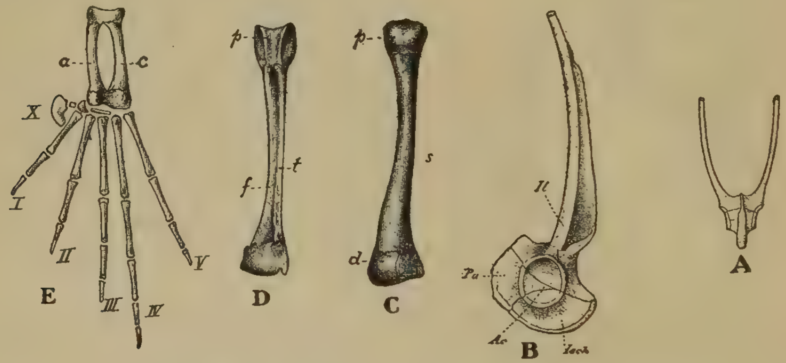


Fig. 22. The Pelvic Girdle and Leg.

A. Pelvic girdle complete.
B. One side of pelvic girdle: *Il.*, ilium; *Isch.*, ischium; *Pu.*, cartilaginous pubis; *Ac.*, acetabulum.
C. Femur of the frog: *p.*, proximal; *d.*, distal articulating surfaces; *s.*, shaft.
D. Tibio-fibula, seen from below: *p.*, proximal; *d.*, distal articulating surfaces; *t.*, tibial half of the bone separated by a groove from *f.*, the fibular half.
E. The right ankle and foot of the frog, seen from below: This figure is drawn to a larger scale than *A* and *B*. *a.*, astragalus; *c.*, calcaneum; *I—V.*, the five principal digits; *X.*, the minute accessory digit. (From Bourne after Ecker.)

The wrist possesses six bones, the **ulnare** ( ), **radiale,** ( ), **intermedium,** and three **carpals** ( ).

The hand has five proximal **metacarpal** ( ) **bones,** followed in **digits** ( ) II and III by two **phalanges** ( ), and in digits IV and V by three phalanges.

The **pollex** ( ) or thumb is rudimentary.

The **pelvic** ( ) or **hip girdle** (Fig. 22) supports the hind limbs, and consists of two sets of three parts each, the **ischium**

( ), **ilium** ( ), and the **pubis** ( ), the latter being cartilaginous, strongly united. The edge of the hip girdle is called the **crest**. The meeting of the two pubic bones forms a **symphysis** ( ). The anterior end of each bone is attached to one of the transverse processes of the arched vertebra. The little cup-shaped opening where the three bones just mentioned meet, is called the **acetabulum** ( ). It is in this concavity that the head of the **femur** ( ), the long bone in the thigh, lies.

The hind limb consists of a **thigh** ( ) with the femur as its solitary bone. The leg proper, running from knee to ankle, is made up of the **tibia** ( ) and **fibula** ( ) fused together, called the **tibio-fibula**, or leg bone.

Note the ridges on these long bones for the attachment of muscles.

There are four **tarsal bones** ( ), the **astragalus** ( ), the **calcaneum** ( ), and two smaller ones.

The foot has five complete **digits** as well as an extra or **supernumerary** toe. Each digit has one proximal metatarsal bone, while beyond these there are a variable number of phalanges. The **hallux** ( ) corresponding to the great toe of man is the smallest of the series. It has one metatarsal and two phalanges. On the inner side of the hallux is the **calcar** ( ), the extra toe. It may have one or two joints and a short metatarsal.

THE MUSCULAR SYSTEM

All movements in the body are produced through the **contraction** of some one or more muscles. The muscles in turn are **innervated** ( ) by one or more nerves. The muscle is usually attached by one or both ends to a bone, so that a good leverage is obtained. In some cases, the attachment is direct, in others by means of a **tendon**, a band of tough somewhat **inelastic connective tissue** which is in reality the continuation of the muscle fascia after the muscle itself ends.

Contraction may be brought about by many causes, such as heat, pressure, electrical, or chemical **stimuli** ( ).

There are three distinct types of muscles (Fig. 23); each type has a more or less individual, cellular arrangement, and these three types are known as **heart muscle**, **voluntary** or **striated** muscle, and **involuntary** or **nonstriated** muscle.

Striated muscle can be moved when the individual possessing it so desires. Such are the muscles of the arm and hand. Examples of nonstriated muscle may be found in the **blood vessels**, where the desire of the individual has little or nothing to do with the contraction and expansion of **circular** and **longitudinal muscles** contained within the walls of the blood vessels themselves.

The outer surface of all muscles is covered by a connective tissue membrane called **fascia** ( ), which is not very elastic, and usually becomes thicker toward the end of the muscle, graduating in a dense, **fibrous band** called a **tendon,** or if this tendon is broad and flat an **aponeurosis** ( ).

That part of the muscle most thoroughly attached—usually to a **relatively immovable part**—and most frequently **toward the center of the body,** is called its **origin.** The **more movable** and **distal attachment** is known as its **insertion.**

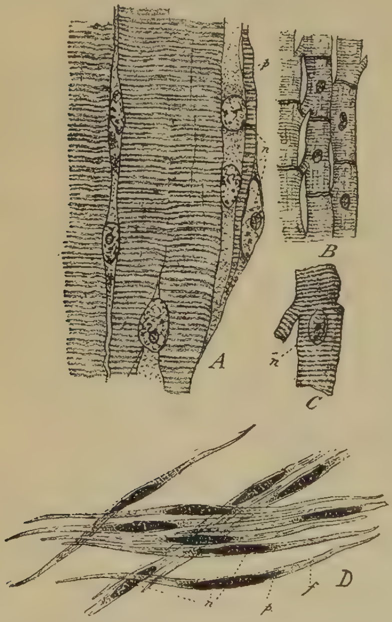


Fig. 23. Different Types of Muscle-Fibres.

A., embryonic striped muscle-fibre from the tail of a tadpole, showing the nuclei *nn.*, and the protoplasm *p.*, of the cœnocyte from which the fibres are developed. The fibres exhibit alternate dark and light bands, and in the centre of each dark band is a light line, the line of Hensen.

B., cardiac muscle-fibre showing the short branched nucleated cells.

C., a single cell from cardiac muscle-fibre more highly magnified, showing the cross-striation and the nucleus *n.*

D., group of unstriped muscle-fibres from the bladder: *a.*, the nuclei; *p.*, the granular remains of the cell protoplasm; *f.*, the longitudinally striated contractile portion. (A and D, from Bourne. B and C from Schafer.)

The action of a muscle in contracting is to draw origin and insertion closer together.

Whenever a muscle moves any part of the body in its normal direction or as one may say, **with** the joint, such movement is called **flexion** ( ); against the joint **extension** ( ). A muscle which pulls any limb or portion of a limb **away from** the **central axis of the body** is an **abductor** ( ), and one which draws the limbs or their appendages **toward the center of the body** is an **adductor** ( ). **Rotators** ( ) are those which cause the limb to **rotate** about its axis such as those turning the femur at the hip; **levators** raise a part such as the lower jaw, and **depressors** produce the opposite movement.

To **know** a muscle there are five points which must be remembered:

(1) Its Origin.
(2) Its Insertion.
(3) Its Relation to other structures.
(4) Its Innervation.
(5) Its Action.

The following list will give the student a clear and accurate idea of what is essential in the study of the muscular system (Fig. 24). The relation of each muscle to surrounding structures can be obtained only by a dissection of them in the animal, and a thorough study of the drawings.

A. MUSCLES OF THE TRUNK

1. Muscles of the lower or ventral side.

(a) Muscles of the abdomen.

e. g. **Rectus abdominis,** a wide band running along the abdomen divided lengthwise down the middle by the connective tissue **linea alba** and transversely by **tendinous intersections.**

Obliquus externus, a broad sheet at each side of the body, arising from an **aponeurosis** known as the **dorsal fascia** which covers the muscles of the back, and inserted into the linea alba above the rectus abdominis.

Obliquus internus and **transversus,** muscular sheets below the external oblique.

By their contraction all these muscles lessen the size of the body cavity and compress the organs within it.

Innervation: All of these muscles are innervated by twigs from IV, V, VI and VII spinal nerves.

(b) **Muscles of the Breast Region.**

e. g. **Pectoralis,** large and fan-shaped, inserted into the deltoid ridge of the humerus and consisting of a **sternal portion** which arises from the pectoral girdle, and an **abdominal portion** which arises from the aponeurosis at the side of the rectus abdominis.

It draws down the arm.

Innervation: Twig from II spinal nerve.

Coraco-radialis, arising from the coracoid and inserted into the upper end of the radius. It bends the arm.

Innervation: Twig from II spinal nerve.

2. Muscles of the Back.

(a) **Muscle inserted into the lower jaw.**

Depressor mandibulae, triangular, arising from the suprascapula and inserted into the angle of the lower jaw, which it draws downwards and backwards, thus opening the mouth.

(b) **Muscles inserted on the fore-limb.**

e. g. **Latissimus dorsi** ( ) triangular, arising from the dorsal fascia and inserted into the deltoid ridge. It draws back the arm.

Infraspinatus, in front of and similar to the latissimus dorsi. It raises the arm.

Innervation: Twig from II spinal nerve.

(c) **Muscles inserted into the shoulder girdle.**

e. g. **Levatur anguli scapulae,** arising from the skull and inserted into the under side of the suprascapula, which it draws forward.

Innervation: Twig from I spinal nerve.

Serratus, arising from the little knobs on the transverse processes of the vertebrae which represent the ribs, and inserted into the under side of the suprascapula, which it draws backwards, outwards, or inwards, according to the division which is contracted.

(d) **Muscles inserted into the hind-limb.**

e. g. **Gluteus** (iliacus externus, or gluteus medius), arising

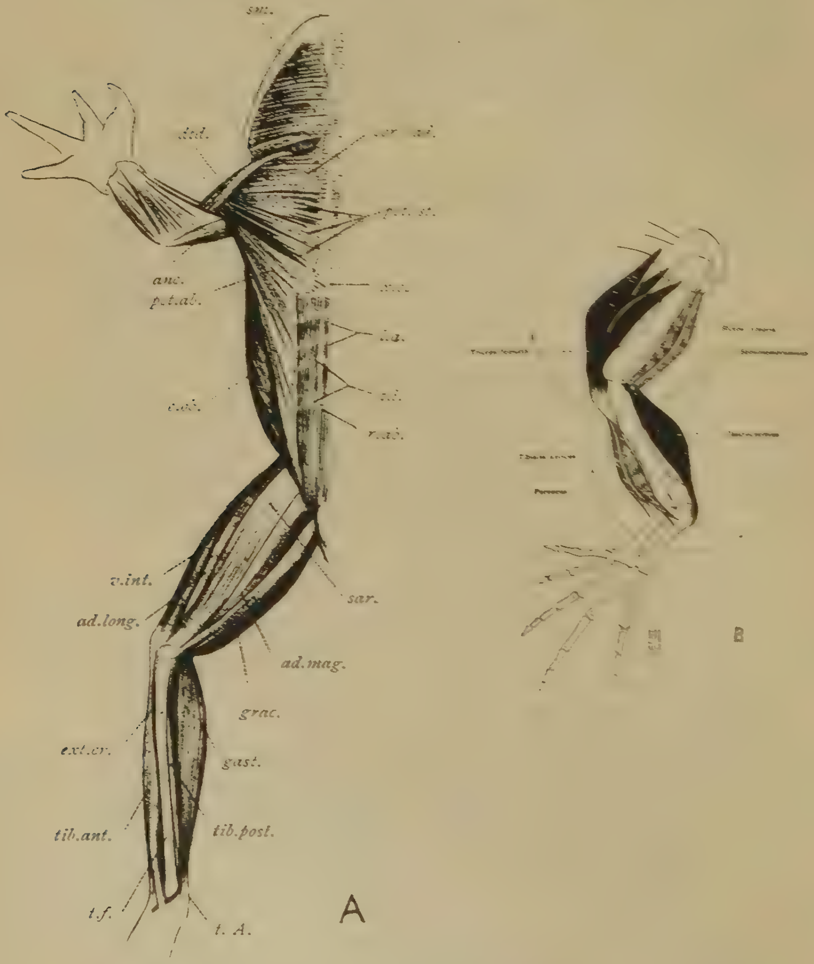


Fig. 24. A—A Ventral View of the Muscular System of a Frog.

ad.long., Adductor longus; *ad.mag.*, adductor magnus; *anc.*, anconæus; *cor.rad.*, coraco-radialis; *dtd.*, deltoid; *e.ob.*, external oblique; *e.cr.*, extensor cruris; *gast.*, gastrocnemius; *grac.*, gracilis; *l.a.*, linea alba; *pct.ab.*, abdominal part of the pectoral muscle; *pct.st.*, sternal part of the same; *r.ab.*, rectus abdominis; *sar.*, sartorius; *sm.*, mylohyoid; *t.i.*, tendinous intersections; *t.A.*, tendo Achillis; *t.f.*, tibiofibula; *tib.ant.*, tibialis anterior; *tib.post.*, tibialis posterior; *v.int.*, vastus internus; *x.c.*, xiphoid cartilage. (After Borradaile.)

B. Dissection of special muscles of the left hind leg of the toad (redrawn from Jammes). Muscles shaded in black are *extensors;* in gray, *flexors.*

from the ilium and inserted into the head of the femur, which it rotates inwards.

(e) **Muscles inserted into the hip girdle.**

e. g. **Coccygeo-iliacus,** arising from the urostyle and inserted into the ilium, which it holds firm as a fulcrum for the movements of the hind-limb.

(f) **Muscles of the Backbone.**

e. g. **Longissimus dorsi,** a band running the whole length of the back, divided by tendinous intersections, which are attached to the transverse processes, and inserted in front into the skull. It straightens the back.

Innervation: Twig from I spinal nerve.

B. MUSCLES OF THE HEAD

1. **Muscles underneath the Head.**

e. g. **Sternohyoid,** from hyoid to pectoral girdle.

Geniohyoid, from hyoid to chin.

Hyoglossus, from hyoid to tongue.

Petrohyoid, from hyoid to auditory capsule.

Mylohyoid, submandibular, or submaxillaris ( ), a sheet of muscle running from side to side of the lower jaw. These muscles alter the position of the floor of the mouth.

Innervation: Twigs from I spinal nerve.

2. **Muscles of the Lower Jaw.**

e. g. **Temporalis** and **masseter** ( ), arising from the skull and inserted into the lower jaw, which they raise.

Innervation: Mandibular branch of the V cranial nerve.

3. **Muscles of the Eyeball** (Fig. 466).

Rectus superior, r. inferior, r. externus, r. internus, arising from the skull in the hinder part of the orbit and inserted into the eyeball.

Innervation: All but the rectus externus from the III cranial nerve. The r. externus by the VI cranial nerve.

Obliquus superior and **o. inferior,** arising from the skull in the front part of the orbit and inserted into the eyeball.

Innervation: Obliquus superior by the IV cranial nerve and o. inferior by the III cranial nerve.

C. MUSCLES OF THE FORE-LIMB

1. **Muscles for the Upper Arm.**

e. g. **Deltoideus,** arising from the scapula and inserted into the humerus. It raises the arm.

2. **Muscles for the Fore-Arm.**

Triceps brachii or **anconaeus** ( ), arising from the scapula and humerus, and inserted into the upper end of the ulna. It straightens the arm.

There is no **Biceps** muscle in the arm of the frog.

3. The **muscles of the Wrist and Fingers** are numerous and complicated.

Innervation: Branches and twigs of II spinal or Brachial nerves innervate all arm and finger muscles.

D. MUSCLES OF THE HIND-LIMB

(1) **Superficial muscles of the Thigh on the Preaxial** (apparent ventral)* **Surface.**

1. **Sartorius** ( ), a long, narrow band arising from the lower end of the ilium, lying obliquely upon the adductor magnus, and inserted into the tibia on its inner side near the end. It bends the knee.

2. **Adductor magnus,** a large muscle arising from the pubis and ischium, lying along the inner border of the sartorius and inserted into the femur near its lower end. It draws the thigh towards the body.

3. **Adductor longus** is a long narrow muscle lying along the outer side of the adductor magnus, and often completely hidden by the sartorius; it arises from the iliac symphysis beneath the sartorius, and unites a little way beyond the middle of the thigh with the adductor magnus. It adducts the thigh and draws it ventrally.

4. **Gracilis major** ( ) or **rectus internus major,** a large muscle arising from the ischium, lying along the inner side of the adductor magnus, and inserted into the inner-side of the head of the tibia. It bends the knee.

5. **Gracilis minor** or **rectus internus minor** is a narrow flat band of muscle running along the inner, or flexor margin of the thigh; it rises from a tendinous expansion connected with the ischial symphysis, and is inserted into the inner side of the tibia, just below its head. Action is the same as for gracilis major.

Innervation: Branches and twigs from the sciatic nerve and plexus.

(2) **Superficial muscles of the Extensor Surface of the Thigh.**

1. **Triceps extensor femoris,** or **cruris,** a very large muscle inserted into the front of the tibia just below the head of the latter, but arising from the pelvic girdle as three separate muscles, the **rectus anterior femoris** ( ), **vastus externus** ( ), and **vastus internus,** or **crureus** ( ). All these lie **on the front of the thigh,** and their action is to straighten the knee.

Innervation: Branches and twigs from the sciatic nerve and plexus.

(3) **Superficial muscles of the postaxial (apparent dorsal) Surface of the Thigh.**

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*The femur of the frog rotates away from the midline more than does the femur of man. Consequently the true outer border of the frog's thigh is equivalent to the inner border of man's. In other words the preaxial surface of the frog's thigh is equivalent to the inner surface of man's.

1. The **gluteus** (iliacus externus), already mentioned, lies in the thigh between the rectus anticus and the vastus externus.

2. The **biceps** (ileo-fibularis) is a long slender muscle which arises from the crest of the ilium just above the acetabulum; it lies in the thigh along the inner border of the vastus externus, and is inserted by a flattened tendinous expansion into the distal end of the femur and the head of the tibia-fibula.

3. The **semimembranosus** is a stout muscle lying along the inner side of the biceps, between it and the rectus internus minor. It arises from the dorsal angle of the ischial symphysis just beneath the cloacal opening, and is inserted into the back of the head of the tibia. It is divided about its middle by an oblique tendinous intersection.

It adducts the thigh and flexes or extends leg according to whether the leg is in a flexed or extended position.

4. The **pyriformis** is a slender muscle which arises from the tip of the urostyle, passes backwards and outwards between the biceps and the semimembranosus, and is inserted into the femur at the junction of its proximal and middle thirds. It pulls the urostyle to one side and draws the femur dorsally.

Innervation: Branches and twigs from sciatic nerve and plexus.

(4) **Deep muscles of the Thigh.**

1. The **semitendinosus** is a long thin muscle which arises by two heads; an **anterior one** from the ischium close to the ventral angle of the ischial symphysis and the acetabulum; and a **posterior one** from the ischial symphysis. The anterior head passes through a slit in the adductor magnus and unites with the posterior head in the distal third of the thigh. The tendon of insertion is long and thin, and joins that of the rectus internus minor to be inserted into the tibia just below its head. It adducts the thigh and flexes the leg.

2. The **adductor brevis** is a short wide muscle, lying beneath the upper end of the adductor magnus. It arises from the pubic and ischial symphyses, and is inserted into the preaxial surface of the proximal half of the femur.

3. The **pectineus** (   ) is a rather smaller muscle, lying along the outer (extensor) side of the adductor brevis. It arises from the anterior half of the pubic symphysis in front of the adductor brevis, and is inserted like it into the proximal half of the femur.

4. The **ilio-psoas** (iliacus internus) arises by a wide origin from the inner surface of the acetabular portion of the ilium; it turns round the anterior border of the ilium, and crosses in front of the hip-joint, where, for a short part of its course, it is superficial between the heads of the vastus internus and of the rectus anticus femoris; it then

passes down the thigh beneath these muscles, and is inserted into the back of the proximal half of the femur. It draws the thigh forward.

5. The **quadratus femoris** is a small muscle on the back of the upper part of the thigh; it arises from the ilium above the acetabulum, and from the base of the iliac crest; it lies beneath the pyriformis and behind the biceps, and is inserted into the inner surface of the proximal third of the femur between the pyriformis and the ilio-psoas.

6. The **obturator** is a deeply situated muscle which arises from the whole length of the ischial symphysis and the adjacent parts of the iliac and pubic symphyses, and is inserted into the head of the femur close to the gluteus.

Innervation: Branches and twigs from sciatic nerve and plexus.

5. **Muscles of the Leg or Shank.**

e. g. (1) **Peroneus,** a long muscle which arises from the end of the femur, lies along the side of the tibio-fibula, and is inserted into the end of the tibia and the **calcaneum** ( ). It extends leg and foot and flexes foot.

Innervation: Peroneus nerve.

(2) **Gastrocnemius** ( ), a large, spindle-shaped muscle which forms the "calf." It arises from the hinder side of the end of femur and tapers into the long **tendo Achillis,** which passes under the ankle joint and ends in the sole of the foot. It straightens the foot on the shank.

Innervation: Tibialis nerve.

(3) **Tibialis anticus,** arising from the front of the femur by a long tendon, lying in front of the shank, and dividing into two bellies, which are respectively inserted into the **astragalus** and **calcaneus.** It bends the foot on the shank.

Innervation: Peroneus nerve.

(4) **Tibialis posticus** arises from the whole length of the flexor surface of the tibia; it ends in a tendon which passes round the inner **malleolus** ( ), lying in a groove in the lower end of the tibia, and is inserted into the dorsal surface of the **astragalus.** It extends the foot when flexed, and flexes foot when extended.

Innervation: Tibialis nerve.

(5) **Extensor cruris** lies along the preaxial side of the tibialis anticus, partly covered by this and partly by the strong fascia of the leg. It arises by a long tendon from the preaxial **condyle** of the femur, runs in a groove in the upper end of the tibia, and is inserted into the extensor surface of the tibia along nearly its whole length. It extends the foot.

Innervation: Tibialis nerve.

6. **Muscles of the Foot.**

These, just as the muscles of the wrist and hand are many and complicated, but the student should know at least the general location of the following:

Aponeurosis plantaris.

The flattened and broadened continuation of the tendon of the gastrocnemius muscle passing over the heel and spreading out on the sole of the foot in a sort of triangle with the base toward the toes.

Where this aponeurosis crosses the heel it is known as the **tendon of Achilles.**

Flexor digitorum I, II, III, IV, V.

Each digit usually has a flexor, extensor, abductor, and adductor bearing the number of the toe to which it is attached, the great toe being **I.**

There are also small **Interosseus** muscles between the various tarsal bones.

For a detailed account of every muscle of the frog see: Ecker's "The Anatomy of the Frog."—(Oxford University Press.)

REPRODUCTIVE ORGANS

The sexes are separate in the frog. The male has a rather thick pad on the underside of its thumb, larger in the spring at the breeding season, than at any other time of the year. The two rounded or oval **spermaries** (A, Fig. 25) of a light yellow color are found at the upper end of the kidneys, while branching masses of a yellow shade are usually attached to them. The **sperm,** the **male gamete** (   ), is produced in the spermaries, being carried through slender **ducts,** the **vasa efferentia,** through the kidneys, emptying into the **ureters.** It will be observed, therefore, that in the male frog the ureters serve **both as an exit** for the **excretion** of the kidneys and the **secretion** of the spermaries. In some species of frogs, the ureters are slightly enlarged, forming a small sac just where they enter the cloaca, and these sacs are known as **seminal vesicles.** The sperm are held there until ready to be discharged.

In the breeding season, if the body of a female (B, Fig. 25), be opened, the **ovaries** are filled with **eggs** and seem to fill almost the entire body-cavity. The ovaries, the female **gonads** (   ), are placed in a position corresponding to the spermaries in the male. If it is not the breeding season, the ovaries are rather small, slightly folded and leaf-life, not very much larger than the spermaries, but of a different shape. The eggs break out of the ovary into the body-cavity and make their way into the **coiled oviduct** through a small opening, passing down into the thin-walled distensible **uterus** (   ). The oviducts themselves are not directly connected with the ovaries, but lie coiled next to the kidneys, the anterior end being a funnel-shaped opening. The tube itself passes caudad beside the kidneys, opening into the cloaca. The uterus is the rather large thin-walled chamber at its termination, in which the eggs are stored after passing through the oviducts until the final egg laying. The oviducts themselves, like the ovaries, vary in size at different seasons of the year.

The **gelatinous substance** covering the eggs is secreted by little glands in the oviducts called **nidamental glands** (Lat. nidus=a nest). It is to be observed that the sexual organs and kidneys lie close together and have a common opening, and in the male the same duct, namely, the ureter, serves for an exit of both sperm and urine. A similar close relation is found in nearly all other vertebrates, and when the study of **embryology** is taken up it will be found that the ducts and kidneys were originally derived from the same region of the embryo. It is therefore common to speak of the excretory and reproductive system together as the **urogenital system.**

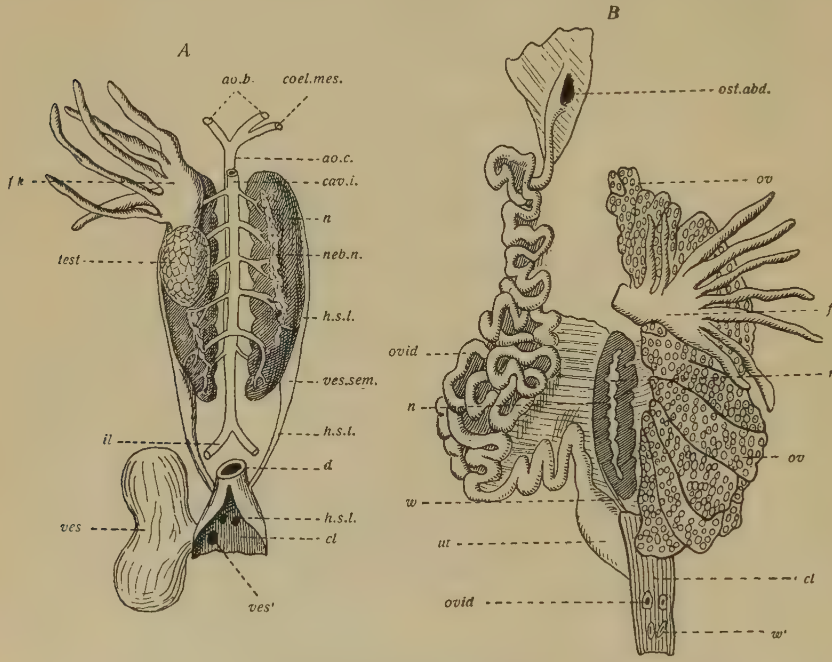

Fig. 25. The Urogenital Organs of the Frog. A, Male; B, Female.

ao.b., systemic arteries; *ao.c.*, main aortic trunk; *cav.i.*, vena cava inferior; *cl.*, cloaca (dissected from the ventral side); *coel.mes.*, coeliaco mesenteric artery; *d.*, large intestine; *f.k.*, fat bodies; *h.s.l.*, urogenital duct; *h.s.l.'*, entrance of urogenital duct into cloaca; *il.*, iliac artery; *n.*, kidney; *neb.n.*, adrenal bodies; *ost.abd.*, funnel-shaped opening of oviduct; *ov.*, ovary; *ovid.*, oviduct; *ovid.'*, entrance of oviduct into cloaca; *test.*, testes; *ut.*, uterus; *ves.*, urinary bladder; *ves.'*, opening of bladder into cloaca; *ves.sem.*, seminal vesicle; *w.*, Wolfian duct; *w.'*, opening of Wolfian ducts. (After W. Meissner.)

THE FAT BODIES

Directly in front of the gonads, we find a yellow organ with many finger-like processes known as a fat body. It has a broader and closer attachment to the anterior end of the male gonad than it has to the female ovary. It is supposed to serve as a storehouse of nutriment, for it varies in size and shape at different seasons of the year. Nearly all the fat disappears from the cells in spring, while as soon as the feeding period begins the fat increases.

References:

Ecker, "The Anatomy of the Frog."
Holmes, "The Frog."
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CHAPTER V.

THE CELL

It will be observed later in the study of the histology of the frog that the different types of cells vary in size and shape, some being round, others more or less cuboidal, still others cylindrical, etc. As there are animals possessed of but a single cell which can nevertheless perform all acts necessary to a complete organism and, consequently, can lead an independent existence, **the cell** is called the **biological unit,** and things in the biological world are not considered explained until they have been reduced to **terms of cell units.**

There is not a living thing, plant or animal, which comes into existence that does not start life as a single cell. It is therefore an **axiom** ( ) of science that there can be no living **cell unless it sprang from a previous cell.** Therefore, an egg, regardless of whether it be the small egg of a frog or so large a one as that of the ostrich, is only a single cell. In fact, in the hen's egg usually used in the laboratory for experimentation, the yolk represents the food for the offspring, the **egg proper** being that little portion, about the size of a dime, which always floats on the top of the yolk, regardless of the position of the egg.

The following drawing (Fig. 26) is that of an **ideal cell.** This means that **everything** which the student will ever find **in any cell,** plant or animal, **is contained in this drawing.** One must remember, however, that search may be made from now until the end of time and **no one cell** may ever be found with all of the parts shown in this ideal cell.

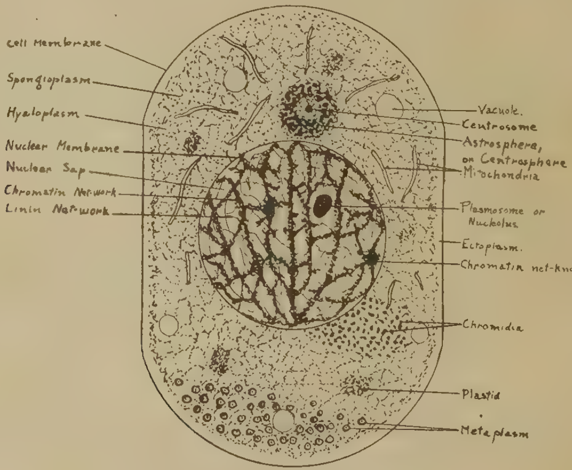

Fig. 26. An Ideal Cell.

The entire substance surrounded by the **cell wall** is called **protoplasm.** This is a jelly-like or **viscous material** something like the white of an egg. Probably most cells have a definite wall, though many animal cells do not. On the inside of this cell wall there is a network, or **reticulum,** in which are found little **foreign bodies, plastids,** and open spaces called **vacuoles.** The network itself is called **spongioplasm,** because it somewhat resembles a sponge. The liquid protoplasm on the inside of this network is called **hyaloplasm** ( ). On the inside of the cell there is a seemingly smaller cell, called the **nucleus.** This nucleus is considered the most important part of a cell. A cell may have one nucleus, or it may have many. There is a **nuclear** wall just as there is a cell wall, and on the inside of the nucleus there is also a network or **reticulum.**

When a cell has been **chemically stained** with various substances, it is found that **a portion of the network in the nucleus takes the stain, while a portion does not,** showing that this nuclear network is composed of at least two different substances. **The part which takes the stain is called the chromatin** ( ) **network,** and the part **which does not take the stain is called linin** ( ) **network.** This nuclear network taking the stain usually stands out quite distinctly from the rest of the cell, making it appear at first glance as though the entire nucleus had taken a great quantity of stain to itself.

The substance lying within the network of the nucleus is called **nucleoplasm.** It may happen that some cells do not have a definitely outlined nucleus with a nuclear wall, but nevertheless these cells have **nuclear material** scattered throughout the cell itself in the form of **granules;** such granules are known as **distributed nuclei.** In the red blood corpuscles of the human being there are no nuclei in the adult form, although these cells **are nucleated** when they originally begin growing.

On the inside of the nucleus there is a **smaller nucleus in turn** which is called the **nucleolus** ( ).

At certain places in the nucleus where the various fibers of network cross each other, there may be little knots, called **net-knots,** and these must not be confused with the nucleoli. The chromatin itself appears in a granular form, and the granules are called **chromomeres** ( ).

There may even be two nucleoli in one nucleus. These stain quite readily also, but appear somewhat different from the chromatin after such staining. Exactly what the nucleolus does, biologists do not know. **It disappears during the time the cell divides** and consequently has been thought to be for the purpose of holding something in reserve for this **division process.**

All of the material **within the cell walls** but **outside of the nucleus** is known as **cytoplasm,** to distinguish it from the **nuclear material** within **the nuclear wall** or membrane.

Just **outside of the nucleus** and **within the cytoplasm**, there is usually found a tiny circle with a dot in the center. The dot itself is called the **centrosome** ( ) and the circle about it the **attraction sphere**, or **centrosphere.**

There are little perforations through the nuclear wall so that there is a direct connection between nucleoplasm and cytoplasm.

CELL INCLUSIONS AND CELL PRODUCTS

Bodies of a solid nature, not protoplasmic, are common to many cells. These are **pigments, oil, fat, crystals, glycogen, starch, chlorophyl, etc.,** and are commonly spoken of as **cell inclusions,** though as a matter of fact only foreign substances such as bacteria, etc., should be called inclusions. Starch and chlorophyl are found almost exclusively in plant cells. By these inclusions the shape of the cell is often changed, and particularly the position of the nucleus. **Fat gathers at one end** of the cell, **crowding the nucleus to the opposite** extremity and displacing the cytoplasm to the periphery, mostly to that end of the cell occupied by the nucleus. **Pigment** may be in solution, more frequently in granules, and always is found in the cytoplasm, **not in the nucleus. Vacuoles** are very common to most cells. These **vary in number and size** and are usually spherical cavities filled with fluid secreted by the protoplasm. The vacuoles **contract, often with considerable regularity,** and, as a rule, empty to the surface of the cell. Waste products are in this way eliminated from the body of the cell.

The constituents of a typical cell may then be summarized as follows:

1. **Cytoplasm,** the protoplasm **that surrounds the nucleus,** consisting of:
   (a) **Spongioplasm,** a reticulum or fibrillar network;
   (b) **Hyaloplasm,** a fluid portion, also called cytolymph;
   (c) **Cell membrane,** often absent in animal cells.[1]
2. **Nucleoplasm** or **karyoplasm,** the protoplasm **of the nucleus:**
   (a) **Nuclear membrane,** frequently absent;
   (b) **Chromatin,** network that stains easily;
   (c) **Linin,** closely allied to the chromatin but does **not** stain; dissolves in distilled water;
   (d) **Nuclear sap,** a fluid perhaps analogous to the hyaloplasm;
   (e) **Nucleolus,** spherical body that stains heavily;
   (f) **Nuclear net knots,** or **karyosomes,** false nuclei that are nodal points formed by interlacing chromatin network;
   (g) **Centrosome,** a small spherical body often found in the cyto-

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[1] Regarding the cell membrane, it is well to know that this is a purely relative term, just as a drop of chloroform in water, or a drop of water in chloroform, or a bubble of air in water, can be said to have a cell membrane. These are really *surface tension phenomena,* where the interphases of water-chloroform, etc., have equal resistance to each other. In the "cell membrane" we really have *naked protoplasm,* tending to round up just as the drop of water does in chloroform.

plasm of animal cells near the nucleus. It is looked upon as the dynamic center in cell division.

If the student is to study Medicine he will probably find an advantage in dividing the various definitely discernible substances in the cytoplasm, into Mitochondria, Plasmosomes, and Paraplasmic substances.

Mitochondria* (Fig. 27). These are little granules, rods, and threads in the protoplasm, **quite constant** in the various cell bodies, at least, of the animal world. In fact, one investigator insists that it is these mitochondria rather than the chromosomes which are the **bearers of heredity**; while another insists that they accumulate at both **poles** of the cell, and are converted into **secretory granules.**

Plasmosomes.† These are tiny granules distinguished from the mitochrondia because they are concerned with the **housekeeping of the cell,** that is, with the assimilation of food materials, with forming various secretions, and with the excretion of waste matter. Plasmosomes have **not been seen** but are supposed to be present because there are certain substances produced in the cells which must be due to something physical or chemical. This is shown by the fact that the products of the cell form little swellings of various kinds. These swellings take a stain and it is the particles which cause these swellings or cell-products which are known as plasmosomes. The cell-products consist largely of fat and carbohydrates, and may be stored in the cells. Cell products are called **cytofacts** or **metaplasm.** (This latter term because such substance is due to metabolism.)

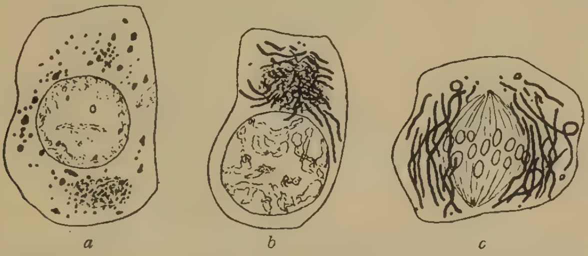

Fig. 27. Mitochondria as They Appear in the Sex Cells of Dividing Sperm of *Blaps*.
a. Scattered granular mitochondria.
b. Rod-shaped.
c. Rods drawn out around spindle. (After Duesberg.)

Golgi apparatus (Fig. 28). Very recently by a special staining method known as Golgi's silver impregnation method, it has been found that there is an "internal reticular apparatus" consisting of a system of

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*While some medical men usually speak of *mitochondria,* and some of the older writers use the term bioplasts, plastidules, archoplasmic granules, plastosomes, plastochondria, chondrioconts, plastoconts and chondriomites, depending on the shape of the mitochondria, the name cytologists use is that of *Chondriosomes,* so that the student must think of *mitochondria* and *chondriosomes* as interchangeable terms.

†Medical men are inclined to use the term plasmosomes as here given, but cytologists use the term only to mean *true nucleoli.* These latter workers never use it in the sense we have given it in this book.

rods or network close to the nucleus, but associated especially with the dense protoplasm which surrounds the centrosome. In epithelial cells the network lies close to the free ends of the cells. The Golgi apparatus is probably found in all animal cells, though little is as yet known about it, except that there is a continuity from parent-cell to daughter-cells by a sort of mitotic division of it quite similar to the regular chromosome division. Prolonged treatment with osmic acid will make the Golgi apparatus visible.

Plastids are differentiated portions of protoplasm representing certain regions in which physiological processes are localized. They are quite common in plants and protozoa. In the former they are usually colored, such as the chloroplasts which are the chlorophyl-carrying organs. Each kind of plastid is supposed to serve a separate type of function.

Attraction sphere and **Centrosome.** These may be quite conspicuous although it is not known whether they are important or not in **cell-division,** shortly to be described.

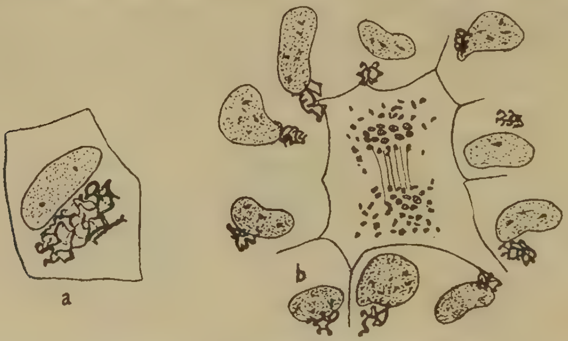

Fig. 28. Golgi Apparatus in Epidermal Cells.
a. Golgi network beside the nucleus in cell of a horse.
b. Same in skin of cat, but broken into small rods around the mitotic figure in the large central cell. (After Deinecka.)

Paraplasmic substances. These are the **foreign substances** which can be seen in the cytoplasm, but **which have not become part of the living** cell itself. Such are granules of **pigment** or **calcium, fat globules, various vacuoles filled with fluid, etc.**

"It is clear that the construction of the cell is highly specialized in most cases for the function which it is to carry out, and that it is supplied with the most perfect mechanisms for these purposes. Some of these are evident in the form of contracted bands in the protoplasm, or in long, nerve processes ( ) like electric wires carefully insulated by sheaths of fatty material, or in mobile cilia which mechanically perform duties in the transportation of foreign particles. In others, the tools of their trade are recognizable in the form of the granules which seem to prepare **ferments** by which the chemical processes which the cells effect are carried out. While these are visible in many cases, there are others, even when we know that the most multifarious chemical reactions are being carried on, in which nothing of the mechanism is recognizable to our eyes."

In plant cells where the cell wall is quite thick, and in some of the animal cells, this cell wall is made up of **cellulose**, a substance quite clearly related to the starches, although there are other substances, such as **lignin** or **silica**, often associated with it, while in the cell walls of animals there is a **nitrogen containing substance**, such as **chitin**, **keratin**, and **gelatin**.

Where there is no distinct cell wall, there may be a **cuticle**, or **pellicle**, covering the entire cell. This may be considered a **lifeless secretion**, just the same as is the cell wall produced by some of the vital activities of the cell itself. The **vacuoles** are little open spaces or **vesicles** of liquid enclosed within the protoplasm. They may be **persistent** or merely **temporary**. In protozoa, vacuoles are quite common. If they enclose food particles, they are called **food vacuoles**. They may, by contracting suddenly, **eject their contents** and serve thus as **excretory organs**. As these vacuoles which eject their contents usually are formed again in the same place, they are called **pulsating** or **contractile vacuoles**.

CHAPTER VI.

THE CHEMISTRY OF LIVING MATTER AND CELL DIVISION

Organic Chemistry, although named after the **organs** of living things, has come to be the study of **carbon compounds.** But as the three great chemical groupings of a living organism consist of **proteins, carbohydrates** and **fats** and all of these contain carbon, a large part of the study of organic chemistry is still devoted to living matter.

One of the great problems of biology is to solve the riddle of how and where life originated. If the stars and planets surrounding our globe were at one time masses of intensely heated matter no life could have been sent from one planet to another. Still it is interesting to know that the first elements appearing on a cooling star are the very ones which go to make up proteins; namely, carbon, oxygen, hydrogen, nitrogen, and sulphur.

It will be remembered that oxygen is the source of most of the energy of an organism, and that the cell is the unit of biology, this cell being made up of various substances called **protoplasm.**

If a substance is of the consistency of glue and **non-crystalloid,** it is called a **colloid.**

Colloids are contrasted with **crystalloids,** such as sugar, salt, urea, etc., in fact, any of those substances which, when in solution, will pass through a membrane.

An **emulsion** is one fluid phase suspended in another. The fluids are said to be in suspension.

Most organic matter is colloidal and some biologists believe that a colloid substance will ultimately be accepted as the biological unit in place of the cell.

Protoplasm, the substance of the entire cell, has somewhat the form of foam, although it differs from foam in having the alveoli filled with a thick liquid substance about the consistency of the white of an egg. The alveoli which make up the foam-like protoplasm, although having very thin walls, have walls thick enough so that diffusion is very slow and the substance itself is different in the alveoli themselves and the spaces between the alveoli.

All protoplasm does not show such alveolar composition. With the ultra-microscope much of the protoplasm appears as tiny particles. It is, therefore, supposed that this homogeneous mass is colloid in character, that is, consists of tiny granules which are suspended in a liquid medium. As there isn't very much difference between a colloid and an emulsion in this case, and as there are cases in which no alveoli can be seen, it is possible that alveolar substance and interalveolar substance may differ about as much or as slightly as a colloid and an emulsion.

The early workers on the cell saw very thin fibers in the protoplasm, and established the "filar" or "reticular" theories of protoplasmic structure. We now know that if the alveoli are arranged in rows the liquid between the alveoli will appear like threads, although we have not been able to find that these so-called fibers have any important function. These theories, therefore, are not among the important biological problems now.

When cells are prepared and stained for study in the laboratory they have many granules distributed within them. These may be coagulation products of the interalveolar protoplasm, or the cut ends of fibers or cell inclusions of various kinds.

The great mass of protoplasm is really an emulsion. The tiny bubble-like particles or alveoli and the liquid in which these float are called by the physical chemist "phases" of a "system." It can, therefore, be understood that the various surface phenomena which interest the physical chemist are to be found in the living cell, and any chemical knowledge of this nature which the student of the cell can obtain will stand him in good stead. Much of the activity of protoplasm can be explained by a study of surface tension.

It is to be borne in mind that protoplasm is never solid, although solid particles may and most often are included within its liquid or semi-liquid mass.

Protoplasm is made up of both **organic** and **inorganic** substances.

Organic.

A. **Always present.**
  - Enzymes.
  - Non-enzymes
    - Carbohydrates,
    - Lipoids,
    - Extractors,
    - Intermediate products of metabolism.

B. **Not always present.**
  - Pigments,
  - Hormones,
  - Aromatic compounds,
  - Toxic compounds.

The enzymes are continually attempting to produce an equilibrium in the cells. They are chiefly protein in nature and speed up the chemical reaction. They may be killed by light or heat. Their activities are **specific,** each type of enzyme doing only one particular type of work. **Every step** in the breaking down of proteids is done by a specific enzyme.

Inorganic.

A. **Always present**, and called **essential elements.**
    H_2O
    Plus C, H, N, K, Ca, Na, Fe, NH_4.
  Minus CO_2, SO_4, Cl, PO_4.

B. **Sometimes present.**
    I, Br, NO_2, NO_3, Zn, Ba, Cu, Mn, As, Fl, Si, Mg.

Muttkowski has summarized the chemical elements concerned in living matter as follows:

I. Elements concerned with Food.
  1. Those which compose food.
    A. Proteins—C, O, H, N, (S, P)—build protoplasm.
    B. Fats—C, H, O—energy and reserve. Certain P-fats enter into building up of all protoplasm (lecithin).
    C. Carbohydrates—C, O, H—energy, and reserve.
  2. Elements concerned in food synthesis.
    Mg, CO_2 (in plants only).
  3. Concerned with food storage—K.
  4. Katalysts—Fe, Ca, Mn, I.

II. Elements concerned with Physiological Processes.
  1. Regulation (turgor, toxicity)—K, Cl, Na, Ca, I, Br.
  2. Sensory—P.

III. Elements concerned with structural relations.
  1. Form relations—elasticity—N, Cl.
  2. Supporting tissues—C, Ca, Si, Mg, P, Fl, (S) in form of phosphates, carbonates, oxalates.

CELL DIVISION

Every living thing, plant or animal, begins its life as a single cell. Therefore it follows that if one wishes to understand how a many-celled animal **(metazoan)** (   ) comes to its adult form of life, one must find an original single cell and follow it throughout all its changes until it has come to adultship.

Every living cell grows if it obtains food, and when it reaches its maximum size splits in two. It may do this **equally** or **unequally**; that is, it may split into a very large and a very small part, or it may split equally into halves of like size and shape. There are then two cells where there was only one before. These two cells then grow until the time they attain their maximum size when the same process is gone through again, so that in a short time there are four cells, then eight, sixteen, thirty-two, sixty-four, one hundred twenty-eight, and so on.

When the children's story is remembered of the blacksmith who was willing to shoe the king's horse on Sunday provided the king would pay one cent for the first nail, and double that for each nail he drove, so that by the time the blacksmith had put in twenty-eight nails, he had won more than a million dollars for the twenty-eighth nail alone, it is easy to understand what a division of cells may bring about in a short time; especially when it is remembered that the tiny **bacteria,** which are **single-celled plants,** may multiply and divide in such way every few minutes. In the course of one or two hours, where division is sufficiently rapid, there are millions upon millions of cells where there was only one before.

Textbooks say there are two ways in which cell division comes about, but recent investigations tend to show that this is in error and that all cell division is **mitotic.** One method was said to be the **shorter** and simpler way, in which the cell, without any previous changes that could be observed, **split in two** parts. But the **longer method,** known as **mitosis** (Fig. 29), is the more common, and is the one which must be studied in detail if any understanding whatever is to be obtained as to how plants and animals evolve from the single original cell to the marvelous complex organisms into which they develop in adult life.

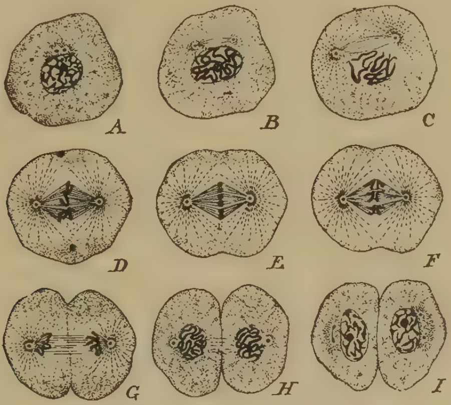

Fig. 29. Diagrams Representing the Essential Phenomena of Mitosis.

A, a cell with resting nucleus containing a chromatic reticulum and a single nucleolus. The centrosome is double and surrounded by the centrosphere. *B*, the centrosomes are separating and each is surrounded by astral rays; the chromatin forms a convoluted thread or spireme. *C*, the spireme is broken up into a number of V-shaped chromosomes, the polar spindle is formed between the now widely separated centrosomes. *D*, the chromosomes attached to the spindle-fibres are arranged at the equator of the spindle. *E*, division of the chromosomes, which are viewed end on. *F*, divergence of the chromosomes. *G*, chromosomes collecting at the poles of the spindle, the space between them occupied by interzonal fibres; commencement of division of cell-body. *H*, *I*, complete division of the cell, and reconstitution of the nuclei. In *I* the centrosomes are dividing preparatory to a new mitosis. Note *A*-*D*=prophase; *E*=metaphase; *F*, *G*=anaphase; *H*, *I*=telophase. (After Bourne.)

The cell, as has just been described in the last chapter, has a network in the nucleus that stains quite easily and readily. In the normal condition such a cell is said to be in the **resting stage.** In the higher forms cell division takes place only after **fertilization,** that is, after the male **sperm** has united with the female **egg.** The **chromatin,** or stained nuclear network, begins a process by which the stained part separates from all of the other network, taking upon itself the shape of a single thread or **skein.** A little later, this skein of chromatin **breaks up into small** particles which may be shaped like a horseshoe or like the capital letter L, or merely appear as little straight or bent rods. These little broken up particles of chromatin are called **chromosomes.** As these chromosomes are **in all probability the most important physical particles** in the study of biology, one must get this subject of **mitosis** and **chromosomes clearly in mind** or all that follows will necessarily be lost.

Just before the cell goes from the **resting stage** into the **skein or spireme stage,** the little centrosomes lying within the centrosphere break into two parts, one part migrating around the nuclear wall until it lies opposite the first half.

Formerly it was thought that it was due to these polar bodies that the chromatin breaks up into chromosomes, but as no centrosomes are found in higher plants, although the chromatin acts just as it does in animal cells, this explanation must be given up. Between these two polar bodies in the animal cell there develops a series of very fine lines which may be only a reflection of some kind, but which one very frequently sees when the cell is undergoing mitosis. These fine lines are called a **spindle,** readily recognized in the drawing. There are four **periods** usually mentioned in cell division:

The Prophases. This is the skein stage already mentioned.

The Metaphase. Immediately after the chromosomes have appeared as small broken particles of chromatin, they gather at the **mid-line** or **equatorial region** of the spindles. Then the chromosomes split in two lengthwise and the cell is said to be in the **metaphase stage.**

The Anaphases. Immediately after the chromosomes have divided lengthwise, one-half of them move toward one polar body and the other half toward the other. During the time the chromosomes have split and the time they have united about the polar bodies, the **cell wall** has indented until it meets the opposite indentation, thus forming two separate daughter cells.* This stage is called the **anaphase.**

The Telophases. This phase lasts from the anaphases until the time the cells again resume the resting stage.

It will be noted that the metaphase is used in the singular, whereas the other three have been used in the plural. This will be readily understood when it is remembered that these terms are only **convenient names** enabling us to discuss intelligently with others the whole subject of mitosis, and, so that when a given thing or event is observed during any particular time of the division of the cells, it can be written and spoken about in an understandable way.

The metaphase is only **that particular moment when the chromosomes have gathered at the equatorial plane** and are dividing. All the other phases cover a much longer period, and, passing through **various stages,** are therefore used in the plural.

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*In plants a new cross cell-wall often originates by a thickening of the central spindle fibres.

In different types of cells, all of these stages vary a little as to length of time and as to the method in which and by which particular **centrosomes, skeins** (also called **spiremes**), **spindles**, and **chromosomes**, arrange themselves. It is well to note also that in the higher forms of plants the centrosomes have not been seen, and that there is a difference between plants and animals in the way the cytoplasm divides. In the **animal cells,** as shown in the drawing, the cell walls **indent** until the two indented portions meet, and the separation takes place in that way; whereas, in the plant cell **this does not indent, but the cell-wall** becomes thicker and thicker until a definite cell wall has been grown for the two new cells.

There are also exceptions as to just **when** and **how** the spindle forms. In some species of **salamander,** the spindle begins **outside of the nucleus,** and then as the **nuclear membrane disappears** the fibers **pass through the nucleus itself.**

THE REAL MEANING OF MITOSIS

The real significance of mitosis is found in the fact that the chromosomes, a more detailed study of which will be taken up as soon as the protozoa have been studied, split in two **lengthwise** and that the chromosomes are **practically the only visible things that pass from a parent cell** to become a new individual. Whatever an offspring is to obtain from its parents **must** therefore be already present in the chromosomes of the various **germ cells** of the parents, or it cannot be inherited by the offspring.

A little later it will be explained also how this lengthwise dividing of the chromosome means that each new individual obtains **one-half** of whatever it is from its mother and one-half from its father, although one's inheritance on the mother's or father's side is usually not evenly distributed as to quantity, and possibly, quality. For example, we may, as far as external appearance go, resemble our fathers, yet have our mother's mental characteristics. One must therefore not confuse the characteristics **which can be seen and are very conspicuous,** with those which **may not be seen,** but **which may nevertheless be much more important.**

By remembering this statement one may understand the biologist's division of all cells in the body into two great groups. These two groups are known as **somatoplasm** ( ) and **germplasm** ( ), the latter consisting of those particular cells which are going to reproduce offspring like the parent, while the somatoplasm consists of all the other cells of the body. It can be imagined from this that it is quite possible for the somatoplasm or outer portion of the body (which is the only portion visible) to **cover up** many **important** or, at least, **latent** and **dormant characteristics** that an individual may have inherited, but which characteristics may **come forth at any** moment. In fact one can understand that such characteristics may lie dormant throughout the entire life of a parent and come forth only in the offspring.

MATURATION AND ELEMENTARY EMBRYOLOGY

Very low in the scale of life there is a differentiation into sexes; the **smaller more active particle** is known as the **male gamete,** while the **larger passive portion** is the **female gamete.**

In all higher forms **fertilization** is our starting point in any discussion of **embryology** or **development.**

There are apparent exceptions to this rule, such as those insects which give rise to young by **virgin birth,** a process called **parthenogenesis** (   ), and in the case of those animals in which several (as high as three) **immature generations may be present at the time of birth. This latter condition** is known as **paedogenesis** (   ).

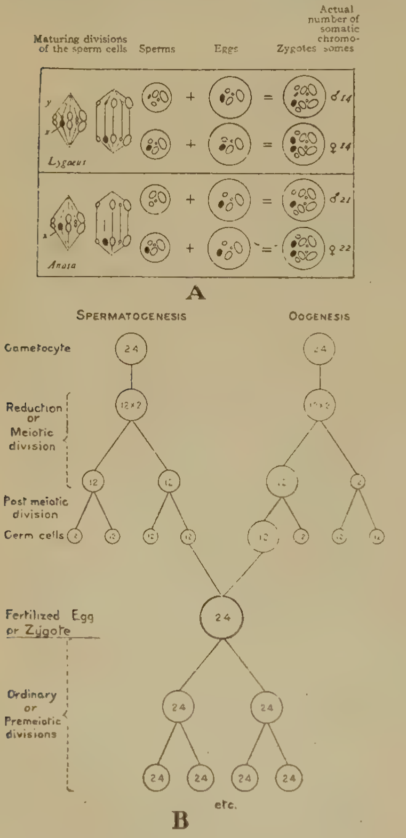

Maturing divisions of the sperm cells
Sperms
Eggs
Zygotes
Actual number of somatic chromosomes
Lygaeus
Anasa
A
Spermatogenesis
Oogenesis
Gametocyte
Reduction or Meiotic division
Post meiotic division
Germ cells
Fertilized Egg or Zygote
Ordinary or Premeiotic divisions
24
12×2
12
etc.
B

Fig. 30.

A. Diagram illustrating the behavior of the "accessory," sex-accompanying chromosome in fertilization. For the sake of clearness, but four other chromosomes are shown, and these four diagrammatically; accessory (x), solid black. (After Wilson.)

B. A diagram of the gametogenesis and fertilization.

Before fertilization various changes take place in the germ cells which are to produce the **mature egg** and **sperm.** This process is called **maturation** (   ), (Fig. 30).

The early cells are called **primordial germ cells.** They are in a **state of rest** in all the higher animals for several years, or until the individual grows to **sexual maturity.** When this time has been reached, there are **three stages through which the primordial cell passes** before producing the mature ovum or sperm.

1. The primordial germ begins to divide **mitotically** (Fig. 31). The resultant cells are called **oogonia** and **spermatogonia.**

2. After a varying number of divisions the many new cells thus produced go through a process of growth. They are then called **primary oocytes** and **spermatocytes.**

3. These then **"ripen"** or **"mature,"** after which fertilization can take place.

From what we shall soon learn regarding **Paramoecia** we know that the chromosomes are the important carriers of all physical **traits** inherited by a child from the parent. But, unless there is some method by which the chromosomes throw **off** one-half their number, each child, being the result of an egg and a sperm mating, would possess everything its mother possessed, plus everything its father had. A **super-race** would thus be produced which in a very few generations would be totally unlike any of its parents. One can imagine what it would mean to have every child twice as strong, and twice as tall, as its parents. It would not be long before men would be thousands of feet tall, and there would be little room for more than one of two people in the world. But Nature apparently loves an **average,** and so somewhere, the chromosomes are halved.

The ripening process is known as the **maturation division** (Fig. 30).

The egg varies from the sperm in the number of complete functioning cells it produces, although the chromatin acts alike in both cases.

From the primordial egg cell only one mature egg develops, while three undeveloped eggs, called **polar bodies,** are formed. These latter degenerate and have no known function. Each sperm cell, however, develops into four complete functional **spermatozoa,** any one of which may fertilize an egg.

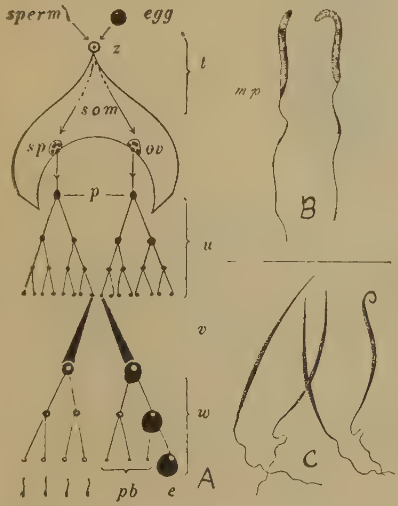


Fig. 31.

A. Diagram of the derivation of the sex cells. ***z.,*** **the fertilized egg (zygote);** ***som.,*** **the body plasm (soma);** ***t.,*** **the development period during which the germ plasm and the body plasm are indistinguishable;** ***sp.,*** **spermary;** ***ov.,*** **ovary;** ***p.,*** **primordial germ cells;** ***u.,*** **the period of rapid increase in number and diminution in size (the number of divisions is much greater than shown);** ***v.,*** **the period of increase in size with differentiation of cytoplasm;** ***w.,*** **the two maturation divisions;** ***pb.,*** **polar bodies;** ***e.,*** **egg. (After Boveri.)**

B. Spermatozoa of ***Rana esculenta.***

C. Spermatozoa of ***Rana fusca.*** **(After Leydig.)** ***mp.,*** **middle piece.**

Notwithstanding this difference, both sperm and egg cell have the same number of chromosomes characteristic of the species. This full quota of chromosomes is called the **diploid number.**

The primordial cells (those which are to become eggs) begin their growth very early in the embryo. Usually, there is a quantity of yolk deposited to serve as food for the embryo which is in turn to develop from the egg.

The chromatin in the nucleus gathers in a thick mass towards one side of the nucleus. This is known as the **synapsis stage.** From this thick mass of chromatin there will emerge just one-half the number of chromosomes usually found in cells of the particular species we are studying. Such cells are said to have the **haploid number** of chromosomes.

Each of these chromosomes is double, the two parts either lying side by side, or end to end. This stage of half the number of chromosomes (but where each is a double chromosome), is called **pseudo-reduction.** Real **reduction** then follows. The two parallel portions of each chromosome divide longitudinally, while the entire chromosome contracts into small four-portioned chromosomes, each of which is called a **tetrad** (Figs. 31 and 33). A mitotic figure now forms and moves toward the outer rim of the egg, the nucleus divides equally, so that one-half of each tetrad passes to a daughter nucleus.

Although the nucleus divides equally, the cytoplasm does not. This produces one large egg cell and one small particle, this latter with one-half the chromatin, but with little or no cytoplasm. The smaller portion is the first **polar body.** This is pinched off from the egg cell proper.

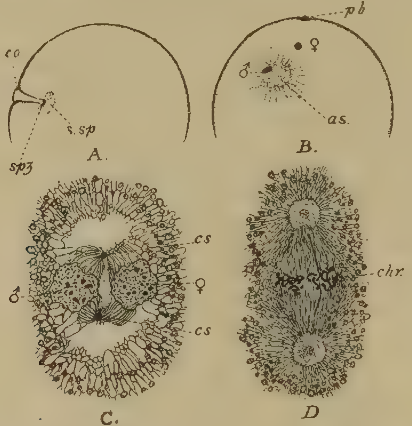


Fig. 32. Fertilization of the Amphibian Ovum.

A, outline drawing of a section parallel to the axis of the egg; the superficial pigment of the animal hemispheres of the egg is indicated, but the yolk granules are omitted. *co.*, entrance cone; *spz.*, spermatozoon lying at the bottom of the entrance funnel; *s.sp.*, spermsphere.

B., a meridional section through the egg at a later stage; ♂, sperm nucleus, also called the male pro-nucleus; ♀, egg-nucleus, also called the female pro-nucleus; *as.*, sperm-aster; *pb.*, polar body. The size sperm-and egg-nuclei has been exaggerated.

C, portion of a section through an egg showing an early stage in the formation of the fertilization spindle, highly magnified; ♂ sperm-nucleus; ♀, egg-nucleus; *cs.*, centrosomes.

D, portion of a section of an egg showing the early stage of the metaphase of the fertilization spindle; *chr.*, the chromosomes derived from the sperm- and egg-nuclei lying unevenly, but still in two distinct groups, in the equatorial plane. (After Jenkinson.)

Both egg cell and polar body now begin to divide again. It is in this second division that each remaining half-tetrad (now called a **dyad**), separates into its two component parts, one going to each daughter nucleus. Thus the second polar body is formed which is also pinched off from the egg cell proper. Often the first polar body again divides to form two tiny cells, but none of the polar bodies perform any actual known function for the organism. From this account we note that there are four cells which have formed from the primordial egg cell—the egg proper and three polar bodies. Two of the polar bodies are the result of the first polar body dividing in turn.

It is of great importance to note that the order of development may change in different species. For example, some polar bodies never divide, while in some species maturation takes place before, and in others after fertilization.

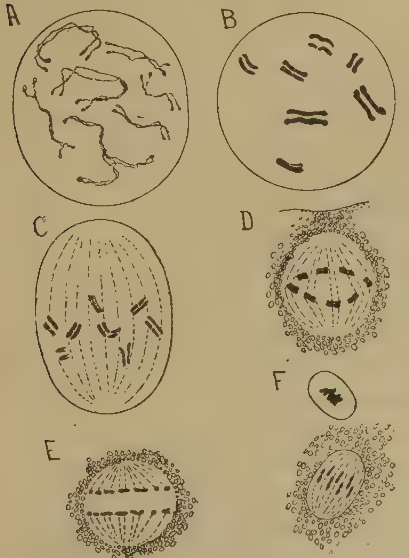


Fig. 33. Maturation of the Egg of *Cyclops* (the full number of chromosomes is not shown).

A, chromosomes already split longitudinally; *B*, chromatin masses with indication of transverse fission to form the tetrads; *C*, the young tetrads arranging themselves on the first polar body spindle; *D*, tetrads in first body spindle; *E*, separation of the dyads in the same; *F*, position of the dyads in the second polar body spindle, the first polar body being really above the margin of the egg. (After Rückert.)

We shall see in our study of plants that this reduction-division is not confined to the animal world.

The male cell—the sperm—passes through similar changes to that described for the egg cell, except that there are no polar bodies formed.

In biology we always think of the reproductive cells as the **germ plasm** which alone carries on from parent to offspring all things that can be inherited. It must therefore follow that there is something in the germ plasm which determines what the offspring is to be. These determining factors must be in the chromosomes, as it is only the chromosomes which pass from parent to child. But there can be a considerable "change-about" of the chromosomes. For example, if we have four chromosomes numbered like this: 1, 2, 3, 4, either 1 and 2 may be thrown out in the reduction division, thus leaving 3 and 4; or 1 and 3 may be thrown out, leaving 2 and 4; or 2 and 3 may be thrown out, leaving 1 and 4; and so on.

If it be remembered that quite a number of combinations can be made in this way in both the egg and the sperm, it is readily understood that there can be several times this number of combinations brought about by a mingling of sperm and egg after fertilization, when the reduced sperm cell unites with the reduced egg cell. When we come to the study of **Genetics** we shall enter into this phase more thoroughly.

It will, of course, depend upon what characters are thus carried by the two mating chromosomes as to what characters the new organism will possess. It is this assorting and rearrangement of chromosomes which is in all probability the cause of **variations within a given species.** This is by no means the same as saying that it is the cause of **new species.** This distinction must be kept clear.

The diploid number of chromosomes is reduced to the haploid number by a union of the chromosomes, two by two. And this union in twos is by no means haphazard. An understanding of this can best be seen in animals where the chromosomes are different both as to shape and size. The squash-bug **(Anasa tritis)** is a good example.

In these bugs the chromosomes occur in two sets, larger ones and smaller ones (Fig. 30). During pseudo-reduction, the larger unites with a larger one, and the smaller with a smaller one, and so on. All the resulting tetrads are symmetrical.

The sum total of all the character-factors which are received from the parents of an animal at the time the egg is fertilized are contained in these two sets of chromosomes. In some insects **virgin birth** is not uncommon. In these cases a complete individual develops from the mature egg alone—that is, from the one having only one-half the definite number of chromosomes normally present in each cell of that species. This shows that each set of chromosomes contains all that is necessary for a complete individual. We, therefore, think that the linking of a similar chromosome from the male and a similar one from the female must be for the purpose of bringing similar important factors together so as to strengthen such factors. A fuller discussion of inheritance will be left for the chapter on Genetics.

FERTILIZATION

The **union or fusion** of the sperm nucleus and the egg nucleus is known as **fertilization** (   ). The spermatozoan is composed of three parts, head, tail, and mid-piece (Fig. 31). The head is largely nuclear material and is the only portion which actually enters the egg and fuses with it. Sperm may enter an egg either before or after maturation of the egg is completed.

After the sperm cells have passed through the maturation process a great mass of them are secreted at one time from the spermaries. If an animal lives in water the sperm float about in that fluid, otherwise enough liquid is excreted to make it possible for the sperm to float about until coming in contact with an egg.

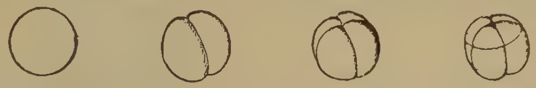
Among all higher animals there are special **copulatory organs** which vary considerably in different animals but which, in all cases, serve to bring egg and sperm together.

There is a great attraction between these germ cells of the different sexes which cause their union and fusion, though what this attraction is has not yet been discovered.

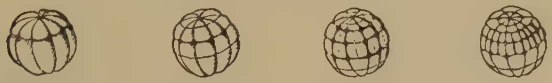
If the sperm enters the egg after the latter has matured (which is by far the more common method) certain changes begin taking place at once.

The sperm nucleus is called the **male pronucleus** (Fig. 32) after it enters the egg while the nucleus of the egg is known as the **female pro-**

nucleus. There is often a special aperture in the wall of the egg called a **micropyle** ( ) through which the sperm enters. Usually only one sperm cell enters an egg. Various changes are set up at the very moment the sperm enters the egg causing the egg membrane to become impervious to other sperm, though sometimes, if the egg be old or diseased, this process may not begin soon enough, so that several sperm enter the same egg. This is called **multiple fertilization.** There are some species in which this multiple fertilization occurs normally. Monstrosities are often formed in this way.



A, one-celled stage *B*, two-celled stage *C*, four-celled stage *D*, eight-celled stage



E, sixteen-celled stage *F*, thirty-two celled stage *G*, sixty-four celled stage *H*, many-celled stage

Fig. 34. Cleavage of Frog's Egg.

When the two pronuclei unite they form a **fusion nucleus** (Fig. 32), also called the **first segmentation nucleus.** The egg is then said to be fertilized, or **impregnated.**

The **full quantity of chromosomes** is now again present and there seems to be an impulse brought with them which starts the egg dividing. This division of the fertilized egg is known as **segmentation** or **cleavage** (Fig. 34). This is brought about by ordinary **mitosis,** and these first cells which come into being by the splitting of the fertilized cell are called **blastomeres** ( ). The chromosomes do not divide longitudinally in these blastomeres but each new cell receives **one-half** of the material brought by each of the parent cells. In this way **every cell** in the body **gets an equal amount** of chromosome material from each of its parents. And in this way also, **every cell** in the body of an individual **has exactly the same number of chromosomes** within it that every other cell has.

Each succeeding division of cells produces cells a trifle smaller than the parent cell.

The cells divide differently with different quantities of yolk. Usually the first **three cleavage planes are perpendicular to each other.** If the yolk is evenly distributed the newly formed cells will be more or less of equal size.

Often the **yolk** collects at the **lower portion** of the egg. This is undoubtedly due to the force of gravity. In such cases the **protoplasm** gathers at the upper end. The **upper end** is then called the **active, formative,** or **animal pole** and the **lower** the **passive, nutritive,** or **vegetable pole.** The **polar bodies** are usually **freed at the formative pole.**

This causes the blastomeres at the nutritive pole to become larger, and divide less rapidly than those in the region where the protoplasm is in excess. In fact the yolk may be so excessive as not to permit any division at all within it.

Two forms of segmentation are usually given:

A. **Total segmentation.**

I. **Equal:** In which there is little yolk material and that well distributed. (Illustrated in most of the lower invertebrates and mammals.)

II. **Unequal:** In which there is a moderate amount of yolk which accumulates at the passive pole. The cells at the active pole are more numerous and smaller than at the passive. (Illustrated in many mollusks and in Amphibia.)

B. **Partial segmentation.**

I. **Discoidal:** In which there is an excessive amount of yolk with the nucleus and a small mass of protoplasm occupying a disc at the active pole. This disc alone segments and the embryo lies upon the yolk. (Illustrated in the eggs of fishes, birds, and reptiles.)

II. **Peripheral:** In which an excess of yolk collects at the center of the ovum, with the protoplasm at the periphery. The dividing nuclei assume a superficial position and surround the unsegmented yolk. (Illustrated in the eggs of insects and other arthropods.)

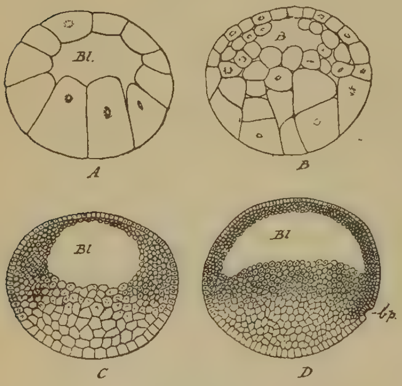


Fig. 35.

A, vertical section through a segmenting ovum in the blastula stage. *B*, *C* and *D*, similar sections through later stages. *Bl.*, segmentation cavity or blastocœle; *bp.*, blastopore. (After Morgan.)

As segmentation continues the blastomeres remain attached to each other and from a **spherical** mass (Fig. 35). If the individual cells **project** out **from the mass** and the sphere is more or less solid, it resembles a mulberry and is called a **morula** ( ), but if it becomes a **single layer** of cells and is **hollow** it is known as a **blastula** ( ). In the latter case the hollow portion in the center is filled with a fluid. The hollow space itself is called the **segmentation cavity.**

If this blastula **indents** (just as though one were to take a hollow rubber ball and push in one side with a finger), there are **two layers in the indented region.** The **outer layer** is called the **ectoderm** or **epiblast,** and the inner the **entoderm, endoderm,** or **hypoblast,** while the entire two layered mass is known as a **gastrula** ( ). The **indentation** is also called **invagination** and **gastrulation** (Fig. 36).

Having indented, the indented portion draws together to form a

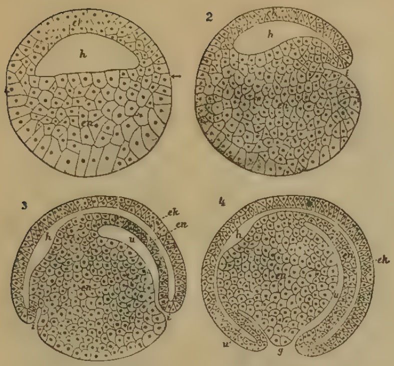


Fig. 36. Formation of the Gastrula in Amphibia, Diagrammatic Longitudinal Section.

1, Blastula; 2, the invagination has begun at *i* (the corresponding place in 1 is indicated by an arrow); the invagination is in the form of a furrow, but does not yet surround the egg; 3, the invagination is proceeding; 4, perfect gastrula; the archenteron is almost filled with a projecting part of the hypoblast, which is later dissolved and absorbed by the embryo. *ek.*, ectoderm (light); *en.*, entoderm (shaded); *g.*, mouth of gastrula; *h.*, segmentation cavity; *i.*, invagination furrow; *n.*, archenteron. (After Boas.)

single mouth-like opening. This opening is the **blastopore** ( ), and the newly made cavity surrounded by **entoderm** is the **primitive intestinal tract** or **archenteron** ( ). In our study of the hydra it will be found that that animal grows thus far and then remains throughout its entire career in the gastrula stage.

In higher forms a **third layer** is formed between the ectoderm and entoderm known as the **mesoderm.** Animals having these three germ layers (Fig. 37) are called **triploblastic** ( ). **All tissues and organs are derived from some one or more of these germ layers.** To study this development is the special province of **Embryology.**

Often certain blastomeres grow more rapidly than others in the same embryo. Such is the case with frog's eggs (Fig. 38). This results in the more rapidly growing cells surrounding those which divide more slowly. A growing of one set of cells over another is called **epibole** ( ). The separation of the germ layers or membranes by splitting apart is known as **delamination.**

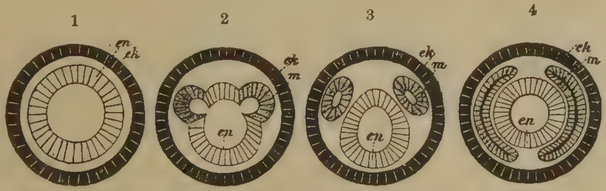


Fig. 37. Diagrammatic Figures in Explanation of the Formation of the Third Germ Layer—the Mesoderm.

1, youngest, and 4, the oldest stage.

ek., ectoderm; *en.*, endoderm; *m.*, mesoderm. (After Boas).

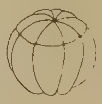


Fig. 38. Frog's Egg, Showing Proportionate Increase of Smaller Cells at Top of Egg.

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CHAPTER VII.

HISTOLOGY OF THE FROG

Every living individual, plant or animal, being able to live an independent existence and possessing the four characteristics of **irritability** ( ), **ability to take and digest food, to grow by intussusception** ( ), and to **reproduce its own kind,** is called an **organism.**

The higher organisms are made up of separate specialized organs, each organ consisting of a series of tissues, and each tissue, in turn, is made up of a sheet of similar functioning cells.

The **cell** is the **biological unit,** and the modern world attempts to explain all living things in terms of cellular construction.

It can be appreciated quite readily that the cell is intensely important in the study of all living organisms when it is realized that **every living thing,** plant or animal, originally grows from a **solitary cell,** and any tiny structure capable of producing so wondrous an animal as the frog or still more wondrous an animal as the human being, is certainly of importance.

In fact, if one could find **all** the **possibilities** of any given cell, and then find **why it has these possibilities,** and just **how and why** it develops into the particular structure that it does and no other, the riddle of life would be solved.

It must be remembered that every living thing starts life as a single cell and then if it is to become a **multicellular animal** it passes through a **cell-dividing stage.** Some plants and animals remain in the one-celled stage, while others, as soon as they begin to divide, **adhere together and form tissues,** which in turn develop into organs. This means that a study of the **origin, development, and content** of the unit cell gives us a sort of bird's eye view of how living things work and grow. A study such as this presents a more complete view than could be procured in any other way.

First, therefore, it is necessary to know the different kinds of tissues that may be encountered; these are grouped under four distinct heads:

1. **Epithelial.**
2. **Connective.**
3. **Muscular.**
4. **Nervous.**

1. **Epithelial tissues** (Fig. 39) are always **surface tissues.** They lie in layers with a small amount of **intercellular** substance. The **surfaces of organs,** the **linings of cavities** of organs, and the **lining of glands, blood vessels,** and **ducts** of all kinds, possess this tissue. In fact, it is

surface tissue whether lying on the internal or external surface of an organ.

There are, however, **various types of epithelial tissue** and these are named from their shape. For example: **Flattened** or **squamous** epithelium easily obtained from the outermost skin of the frog during the time it molts, or from the peritoneum, is composed of cells which are broad and flat with a rounded **nucleus** near the center.

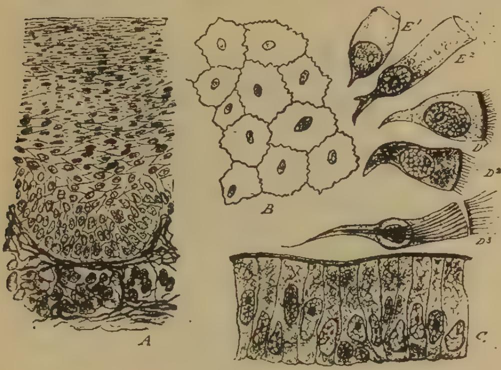

Fig. 39.

A, stratified epithelium from the oesophagus of the rabbit, seen in section. In the lower part of the figure the connective tissue and muscular layers are shown. B, squamous epithelium from the mesentery of the Frog, silver nitrate preparation; *E1*, *E2*, goblet cells from the frog's mouth; *D1*, *D2*, isolated ciliated epithelium cells from the frog's mouth; *D3*, an isolated ciliated cell from the gill of the mussel. C, columnar epithelium from the intestine of the frog. (From Bourne, after a drawing by Dr. E. H. Schuster.)

In the mucous layer of the intestine, we find what is known as **columnar** epithelium, because the cells are shaped like columns, while in many places such as in the outer skin, there are **transitional stages** between these two types of tissues which have some of the characteristic shape of both flat and columnar epithelium.

If these cells are several layers deep they are called **stratified epithelium.**

Should they have tiny hairlike substances called **cilia** at their outer ends they are known as **ciliated** epithelium. These may be almost any shape—**columnar, cuboid** or **flattened.** Ciliated epithelium is found in the **mouth, throat,** parts of the **peritoneal lining** of the body-cavity, inner lining of the **oviducts,** in the mouths of the ciliated funnels of the **kidney,** in the **ventricles** of the brain, and, in very early life, even on the outer surface of the body.

2. **Connective tissue** (Fig. 40) serves to support and hold together various parts of the body. In this type of tissue, the **intercellular substance** is quite abundant as contradistinguished from nearly all other types, and it is interesting to note that nearly all of the connective tissue is derived from the middle **germ-layer** or **mesoderm** (   ). The intercellular substance changes in many ways, remaining soft, or becoming **fibrous and even changing into bone.** The principal types of this tissue are as follows:

White fibrous connective tissue, most widely distributed, and easily obtained from the membranes connecting skin and body-wall. Under the microscope it appears as a clear gelatinous substance in which many fibrils are embedded. The fibrils are **unbranched** but have a characteristic **wavy appearance**; often they are united in bundles and run in all directions. A few **yellow elastic fibers** may be scattered among the white. These are always **straight,** however, and not wavy. If the tissue should be treated with acetic acid, the white fibers swell up and disap-

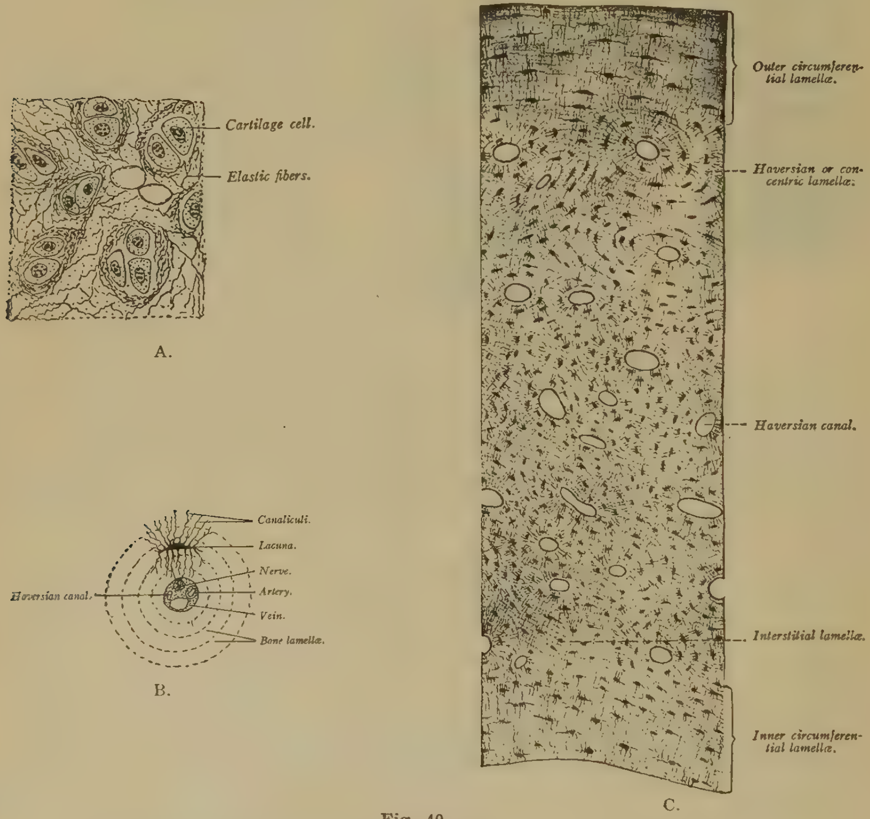

Fig. 40.
A. Elastic Cartilage.
B. Haversian system with one lacuna sketched.
C. Segment of transversely ground section from shaft of a long bone, showing all lamellar systems. (From Böhm and Davidhoff).

pear. The **yellow are not affected.** The yellow fibers may also branch, and when cut they **do not curl** as do the white fibers. In the various spaces of the **matrix** (   ) **connective tissue corpuscles** or cells may also be found, varying in form and appearance, often united with neighboring cells to form an **irregular network,** the meshes of which are filled with intercellular substance. White fibrous tissue varies in **consistency** and **texture** in different parts of the same animal. The loose tissue binding muscles together is known as **areolar** (   ), being composed of sheets and strands intersecting each other in all planes. It is this that forms the **fascia** for each muscle, being modified into a **tendon** at the end.

The looser tissue of the lymphatic glands is called **adenoid** ( ) and is composed of an irregular network of sheets and strands which forms a fine meshwork of supporting cells.

The various **ligaments** uniting the bones are formed of a dense and non-elastic variety of white fibrous tissue. It is also found in the **cutis** of the skin, the **submucosa** of the alimentary canal, in the walls of the blood vessels, in the substance of glands, and in the capsules covering various organs.

Adipose tissue is regarded as a form of connective tissue in which the cells have enlarged by being gorged with fat. The nucleus here lies toward one side of the cell, while the cell-wall and a thin **pellicle** of **protoplasm** surround the **fat globule.**

Cartilage is a dense and massive variety of connective tissue. The predominant type in the frog is known as **hyaline** ( ), the **matrix** of which appears **transparent** and **homogeneous** ( ), although it really consists of numerous fibers of different types which can only be observed after various chemical experiments have been performed upon it. The cells in this type of tissue are contained in little rounded spaces or **lacunae** scattered quite irregularly through the matrix. There may be two or more cells in one lacuna, causing us to believe that the cells may have quite recently been formed by a division of the parent cell. An intercellular substance is deposited around each cell, there being a sort of partition grown between each of the cells which gradually increases in thickness and presses them farther and farther apart. The outer surface of the cartilage is covered by a thin layer called the **perichondrium** ( ).

Hyaline cartilage is found at the **ends of the bones** of the limbs, between the spinal vertebrae and **the ends of their transverse processes** at the **tip of urostyle,** in the **pubis** of the pelvic girdle, in the **hyoid,** and the **cartilage of the larynx** and of **both ends of the sternum.** It also forms the **basis of the cranium** and the **central axis** of the **lower jaw.**

Calcified cartilage is that which contains a deposit of **lime salts in the matrix.** It is found in the **pelvis of old frogs,** in the **suprascapula** and at the **ends of the larger bones** in the limbs such as the head of the humerus and femur.

Bone structure is quite similar to that of cartilage and also contains cells embedded in a solid matrix. In bone, however, the matrix is made more firm by a deposit of **carbonate** and **sulphate of lime.** If the bone is immersed in acid the lime solids are removed, the histological structure of bone is quite like that of cartilage. It does not follow from this, however, that bone is merely calcified cartilage, for bone and cartilage differ from each other both histologically and chemically. Cartilage often is followed by bone, but when it is, the cartilage has been broken down and the bony tissue has taken its place. We speak of two types of bone, namely, **compact,** and **spongy** or **cancellous.** The former is firm and dense; the latter being composed of a comparatively loose arrangement of plates and parts, lacks the strength of compact bone. The spongy or cancellous type is found in the **center of the vertebrae** and to a small extent within some of the long bones. Bones such as the femur and, in fact, all of the long supporting bones in the body, must be rather compact. A cross section of any of these long bones will show the outer hard portion of a compact bone with an inner soft **marrow** and a thin surface layer over the outside called the **periosteum** ( ), quite similar in structure to the perichondrium surrounding cartilage. The arrangement of the layers in compact bone is **concentric**, and the layers themselves are known as **lamellae** ( ). These lamellae contain numerous lacunae in which the bone-cells proper are found. Fine branching tubes or **canaliculi** containing processes from the bone-cells are given off from the lacunae and extend in all directions, often **anastomosing** ( ) with the neighboring canaliculi.

Bones grow like trees in that there are succeesive layers added to the outside. The cells forming the inner layer of the periosteum, known as **osteoblasts** ( ), are continually giving rise to new bone cells, which cause new layers of bony substances to be deposited between the periosteum and the old bone. New layers may, however, be added on the inner surface between the walls and the marrow cavity.

Muscle tissue (Fig. 41) is composed of elongated cells or fibers united by connective tissue, as already mentioned. There are three types, the **voluntary or striated,** the **involuntary or unstriated,** and the **automatic or branched,** a sort of combination of these two known as **heart-muscle.**

The nonstriated fibers are rather simple in structure, commonly **spindle-shaped** with a single nucleus near the center, often elongated. The ends of the fibers may be branched, but are not usually so. The length of the fibers varies to a considerable extent. They may be very narrow, or short and comparatively thick. In the involuntary muscle fibers there is usually no cross striation, but one may find delicate longitudinal strands called **fibrillae,** usually considered to be the **contractile elements** of the cell. The cell wall itself is thin and transparent. Nonstriated muscles respond to stimuli quite slowly, being also somewhat slow to relax after the function has been performed. It is found particularly in those branches of the body where sudden movement is not required, such as in the **muscular coats** of the **alimentary canal,** in the **walls of blood vessels,** in **various ducts,** in the **lungs, urinary and gall bladders,** and around **glands in the skin,** and also in the **iris** and **ciliary muscle** of the eye.

Striated muscle fibers are more complicated in structure. They possess several **spindle-shaped nuclei** scattered throughout the cell, each nucleus surrounded by a small amount of **undivided cytoplasm** ( ).

There is a thin but well defined cell wall called the **sarcolemma** ( ), best seen where the contents of the fiber are crushed or broken apart.

Each fiber of voluntary muscle is regarded as a single cell with numerous nuclei scattered throughout its cytoplasm. In the early stages of development there is but one nucleus in each cell in the voluntary muscle, but as the fiber grows and the nucleus rapidly divides, while the cytoplasm does not, there are naturally a number of nuclei within a single cell wall.

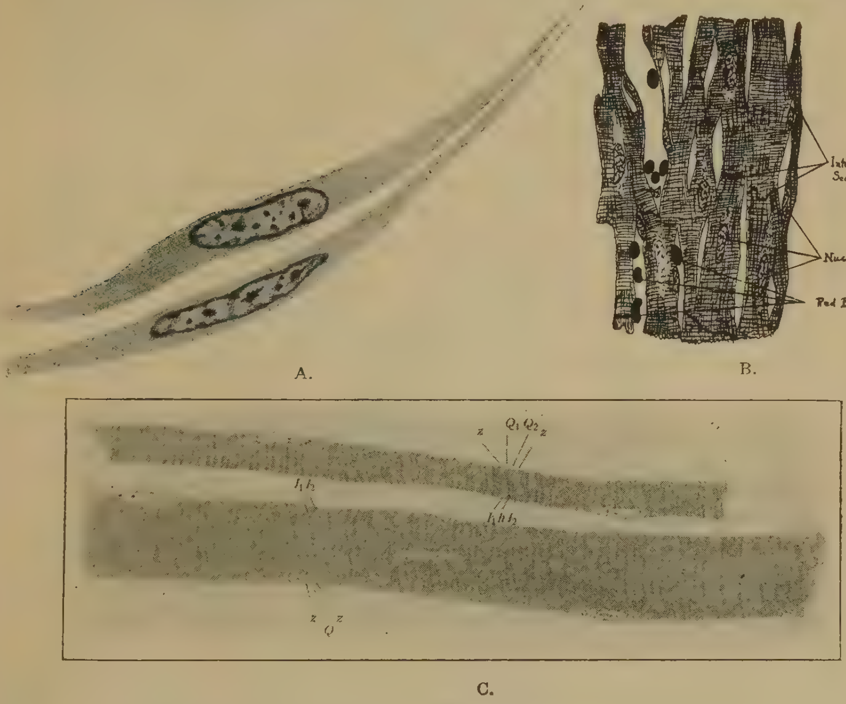

Fig. 41.

A. Smooth muscle fibers from the bladder of a Frog.
B. Heart-muscle syncitium.
C. Striated muscle fibers from the muscle of a cat. Q, cross discs separated from each other by interposed discs *I1, I2*. *zz* shows the stripe in which granules are visible. H, is shown as a center-disc, situated within the cross-disc. (From Krause-Schmahl "Histology," by permission of The Rebman Co.)

There is here **both a longitudinal** and a **cross striation** consisting of alternate light and dark bands. **Sarcostyles** ( ) or **fibrillae** which extend the entire length of the cell are the cause of the longitudinal striations. These fibrillae, as in the unstriated muscle fibers, are the contractile elements and they are kept apart by a semifluid substance called the **sarcoplasm.** The fibrillae themselves are arranged in bundles or muscle columns separated from each other by a thicker layer of sarcoplasm than is found between the fibrillae. The cross striation is due to the fact that the fibrillae really consist of seg-

ments or sarcomeres ( ). The segments are separated from each other by a very fine dark line called **Krause's membrane.** This membrane extends not only across the individual fibrillae but across the entire sarcoplasm between the fibrillae of the fiber. Krause's membrane is bordered on each side by a more or less clear and **lightly stained band** formed by the ends of the two adjoining segments. The middle portion of each segment forms a so-called dark band, and across the center of this band there extends a second very delicate membrane known as the **line of Hensen.** Should the muscle fiber be cut transversely, the cut ends of the muscle columns present a number of **polygoneal areas** known as **Cohnheim's fields.** The spaces between the fields are filled with sarcoplasm and the dotted appearance is due to the cut ends of the tiny individual fibrillae.

The **muscle fibers of the heart** are different from either the striated or unstriated fibers. Heart muscle presents cross striations, although, contrary to the ordinary striated muscle, **each fiber possesses more than one nucleus.** Further, every heart muscle cell has branches which connect with other branches, thus forming a continuous network called a **syncitium** ( ). (A syncitium represents a group of cells whose separating walls or membranes have been lost, resorbed, or failed to form.)

4. **Nerve tissue** (Fig. 42) is made up of nerve fibers and **ganglion cells** ( ). A nerve cell, together with all of its processes, is called a **neuron.** Each nerve is made up of a bundle of fibers held together by connective nerve tissue and surrounded by a common sheath. The central strand of a nerve fiber is called the **axis cylinder.** About this is found the **medullary sheath** ( ), (also called the **white substance of Schwann)**; then a delicate external membrane called the **neurilemma** or **sheath of Schwann.**

There are various **constrictions** to be seen in any long nerve known as the **nodes of Ranvier.** This is where the white substance is interrupted although the axis cylinder and neurilemma continue.

The nuclei surrounded by a small amount of protoplasm are found immediately beneath the neurilemma. There are also various **oblique markings** across the medullary sheath between the nodes of Ranvier known as **incisures of Schmidt.** The axis cylinder of a nerve is merely a continuation of a ganglion cell, being made up of very fine fibrillae, with an intervening fluid substance. The white or medullary substance contains a large amount of fatty material called **myelin** ( ). This sheath is supposed to act somewhat as an **insulator.**

Nerve fibers **and muscle** fibers **develop differently,** the former being a **composite structure** formed of cellular elements that originate in various ways. For example, the nerve sheaths, though coming in contact with, and surrounding the axis cylinder, have a totally different origin from the cylinder. It is interesting to know that in its development the

axis cylinder is the first to make its appearance and comes from the exterior or ectodermic layer of the organism in which it develops, while the cells forming the sheath come from the mid or **mesodermic** layer.

The **negative manner** of testing any of our scientific laws and principles may be illustrated here by calling attention to the fact that much of our knowledge of the position of nerves in various parts of the body does not come from our ability actually to trace them throughout their entire course, but by tracing the **dying** portion of an **injured** nerve. Having found that the cell is the important part of a nerve, and that whenever a fiber is cut between its cell and the termination of its processes it is that part still attached to the cell which will grow again, experimenters have cut nerve fibers and then watched that portion no longer connected with the cell proper, degenerate. By watching this and then observing those parts of the body that degenerate along with the dying nerve fiber, it is easy to see where the fibers actually pass and terminate.

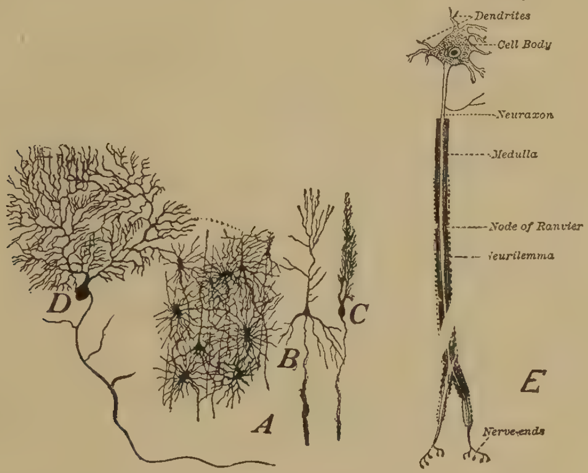

Fig. 42.—*Neurons of Various Types* from Higher Animals.

A, a complex of neurons from the cerebrum; B and C, neurons from the cerebellum; D, a single neuron from the cerebrum. E, diagram of a neuron or nerve unit.

Nerve centers is the name given to those parts where several nerve cells are grouped together such as the brain, spinal cord, ganglia, and the various ganglionic masses of the sympathetic system. The centers themselves consist of ganglion cells and their fibers, together with the connective tissue which holds them together, and the little vessels which supply them with nutriment and carry away waste products.

Ganglion cells are usually quite **irregular** in outline with a **single nucleus near the center.** The **cytoplasm** is **rather granular** and with certain stains shows a network of tiny fibers connected directly with the fibrillae of the nerve fiber as well as with other processes of the cell. There are several kinds of processes. The **axis cylinder process** already mentioned, which requires a sheath and becomes part of a nerve fiber, and the **protoplasmic processes,** sometimes several in number, which are shorter than the axis cylinder and usually branched.

The cells themselves are designated as **unipolar, bipolar,** or **multipolar,** in accordance with the number of processes they may give forth. Unipolar ganglion cells are found in the sympathetic ganglia.

CHAPTER VIII.

SUMMARY OF THE FROG

It has now been seen that the frog is a **cold-blooded** animal, an **amphibian,** and a **vertebrate.**

Its **external features** have been observed.

Its **internal structure** consisting of a series of organs known as **systems** have been studied. These were:

(a)	Digestive.	Concerned with Metabolism.
(b)	Circulatory.	
(c)	Respiratory.	
(d)	Excretory.	
(e)	Nervous.	Concerned with regulation and control.
(f)	Endocrine secretions.	
(g)	Muscular.	Concerned with locomotion, support and protection.
(h)	Skeletal.	
(i)	Integumentary.	
(j)	Reproductive.	Concerned with the propagation of the race.

It has been learned that organs are composed of **tissues,** and tissues in turn, of **sheets of similar functioning cells.**

There were four general types of tissues:

(a) **Epithelial.**
(b) **Connective.**
(c) **Muscular.**
(d) **Nervous.**

Tissues may also be classified according to their **functional** and **structural** character. For example, according to **function,** the epithelium is grouped as follows:

(a) **Glandular,** which consists of **secreting** cells.
(b) **Sensory,** which consists of sensory nerve cells and their fibers.
(c) **Germinal,** which consists of those cells having especial growth or reproductive ability.
(d) **Protective,** which goes to make up an outer covering of an organ or of the body itself.

According to **structure:**

(a) **Cuboidal,**
(b) **Cylindrical,**
(c) **Columnar,**
(d) **Squamous,**
(e) **Stratified,**

Connective Tissue is known as

(a) **Cellular,** when it is composed almost entirely of cells with little substance in between them.

(b) **Homogeneous,** if the entire substance looks very much alike.

(c) **Fibrous,**

(d) **Cartilage,**

(e) **Bone.**

The **Muscular Tissue** is divided into:

(a) **Striated or Voluntary.**

(b) **Non-striated or Involuntary.**

(c) **Heart Muscle.**

The **Nervous Tissue** consists of cells known as:

(a) **Unipolar,**

(b) **Bipolar,**

(c) **Multipolar.**

Some writers call **blood and lymph** cells (Fig. 43) a fifth type of tissue.

Red Corpuscles (erythrocytes) ( ) (causing the characteristic red color of the blood) occur almost only in vertebrates. (In invertebrates, such as the earthworm, the **blood-plasma** is red.) The red corpuscle has **no nucleus in the mammal while in other vertebrates it** has.

White Corpuscles (leucocytes) ( ) are **wandering cells in the blood and lymph** which are **phagocytic** ( ) in their action, that is, they assist in keeping the body in health by devouring foreign substances.

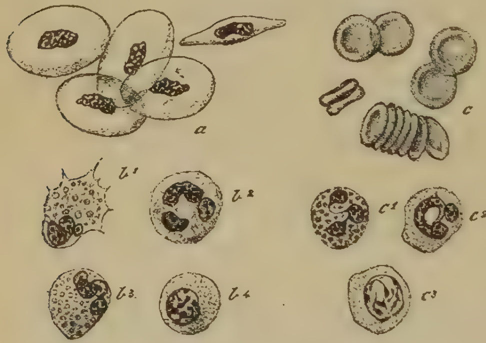

Fig. 43.

A, Red blood corpuscles (haematids) of the frog, stained with safranin and much magnified, to show the nucleus and nuclear network. *b1*, an amoeboid coarsely granular leucocyte from the frog's blood, showing trifid nucleus; *b2*, *b3*, *b4*, other forms of leucocyte from the frog's blood. c, discoid non-nucleated haematids from human blood, much magnified; *c1*, *c2*, *c3*, different forms of leucocytes from human blood. (After Bourne).

The various organs of the body are responsible for the particular **size, shape,** and **function** of the animal possessing them.

There are two ways of looking at an organ:

(a) **Morphologically,** or according to its **structure** or anatomy.

(b) **Physiologically,** according to the **function** such organ may perform.

If organs of different animals are **physiologically equivalent,** that is, if they **function similarly,** they are known as **analogous** organs.

If the organs of different animals are **morphologically equivalent,** that is, if they have **developed** in a similar manner in relation to the other structures immediately surrounding them, they are called **homologous** organs.

There are **three possibilities** in comparing animals:

(a) The organs may **at the same time be homologous and analogous.**

(b) They may be **homologous but not analogous,** as for example the swim-bladder of fishes and lungs of mammals.

(c) They may be **analogous but not homologous,** as for example the gills of fishes and the lungs of mammals.

The **functions of organs** are classified as follows:

(a) **Vegetative,** found in plants. These have to do principally with growth.

(b) **Animal,** being those functions which are absent in plants or but very **slightly developed,** while in the animal kingdom they are considerably increased or are totally separate and distinct from anything the vegetable world may possess.

The **vegetative functions** are equally complete in both man and the lower animals although they may **develop quite differently** in the two groups.

Animal functions are those of motion and sensation. The work of the various **specialized sense organs,** such as the eye and ear, come under this grouping, while the work of those organs which pertain to **nutrition** and **reproduction,** which both plants and animals possess equally well, are vegetative.

Living matter has been shown to have four distinguishing characteristics:

(a) **Irritability,**
(b) **Growth by intussusception,**
(c) **Reproduction,**
(d) **Nutrition.**

When nutrition is discussed biologically it must be thought of in its widest sense as including **not only** the **taking in of food and drink,** and the digestive process consisting largely of fermentation and the absorption of such digested food, but also as including the taking in of oxygen through the respiratory tract to cause heat and energy, and the distribution through the circulatory system of the blood (the real nourishment of the body) and finally, there must be included the excretory system which eliminates all that for which the body has no further use.

An **organism** was defined as **any living thing capable of leading an independent existence.**

If it is living matter it must have the four characteristics mentioned.

The frog is one of the **higher organisms** made up of organs, which in turn are made up of tissues consisting of sheets of similar functioning cells.

In the frog each group of tissues has a definite work to perform, i. e., the eye **only** sees and the ear **only** hears, the bones **only** support, and the heart **only** pumps blood.

This **specialization** in the work of an organ is known as a **division of labor.**

There are hundreds of thousands of animals so small that they cannot be seen with the naked eye, many of which are composed of **only a single cell.**

As they have **only one cell** they can have no tissues and consequently no organs. But if they are living things they **must** possess the four characteristics which distinguish living matter.

They do have these four distinguishing characteristics. Consequently the single-celled animal is as truly a living organism as is the frog.

But, as there are no organs and no tissues, the **protoplasm in this single cell must be able to do all the different kinds of work that the different organs in the frog do.**

Therefore, in one sense of the word, the single-celled animal which is able to do all that a many-celled animal can do without any of that many-celled animal's organs, is much more complex and remarkable than is the so-called higher form.

And lastly, even those organisms highest in the scale of life begin that life with a single cell which in turn grows by that cell dividing and becoming two, these two four, these four eight, and so on until the complete adult is reached.

With this summary in mind we may take up the study of the single-celled organisms.

CHAPTER IX.

THE PROTOZOA
AMOEBA

Just as the frog is easily obtainable and most frequently studied in the laboratory, so the **Amoeba** (Fig. 44), because it may be found anywhere, is one of the most classic forms of **uni-cellular life** that is made use of in the laboratory. This single-celled animal has all of the four characteristics necessary for a living being. It is found almost **anywhere** but **it does not follow that it is found everywhere.** In fact, unless particular arrangements are made to have the **Amoebae** ready at the time they are wished for study, the probabilities are that they will not be found where one is looking for them.

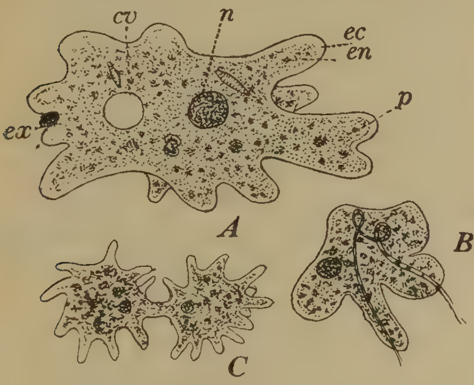

Fig. 44. *Amoeba Proteus.*

A, the animal in its natural condition; B, an animal that has swallowed a long filamentous plant; C, the animal in the state of division.
cv, contractile vacuole;
ec, ectosarc;
en, endosarc;
ex, remains of undigested food;
p, protoplasm. (After Conn.)

Just as with the frog, so with a single-celled animal, we attempt first to study its anatomy or morphology. We want to ascertain what **seeable parts** go to make up this tiny animal. We find in it all the constituents of a cell and all the needed characteristics to make an organism.

There is an outer colorless layer of clear cytoplasm, called the **ectosarc** (   ), then a large central mass of **granular cytoplasm,** known as the **endosarc** (   ). A **contractile or pulsating vacuole** will usually be found lying in that part of the animal **opposite the part that is moved** most frequently. There may be several **food vacuoles,** various **foreign substances** such as grains of sand, and undigested particles (this latter depending, of course, upon whether the animal is studied immediately after it has been feeding extensively). Then there is also some material which has been **digested** and is ready for **excretion,** and a **nucleus.** The nucleus is not easily distinguishable in living **Amoebae.** For this purpose animals are killed and **stained, mounted upon slides,** and studied very carefully with the **compound microscope.**

The nucleus changes with the various movements of the animal, so that it will not be found in the same location in all **Amoebae** studied. It has a rather **firm nuclear wall** or membrane and there are quite a number of spherical particles of **chromatin** scattered about in the **nuclear sap.** The **contractile vacuole** usually lies near the nucleus, but as the vacuole grows it becomes further and further separated from the latter, and by the time it is ready to contract and expel its contents, lies close to the end farthest from the **pseudopodia,** or, what is commonly called the **posterior end.** It then re-appears close to the point of its disappearance, being carried along by the **streaming protoplasm** back to a position near the nucleus, again passing through the same stages just described.

The fluid content of the contractile vacuole contains **urea.** As this is the common **excretory substance** of all animals we know that the contractile vacuole is excretory. It is also **respiratory** because CO$_2$ in all probability passes to the exterior of the body by way of this organ, the oxygen itself being taken in through the outer surface of the body. It is well to compare **Amoeba's** physiological functions with the respiration of a higher animal, such as the frog. The food vacuoles come into existence whenever food is taken into the organism, each vacuole seemingly acting as a **temporary stomach.**

MOVEMENT

The **ectosarc,** also called **ectoplasm,** sends out **finger-like projections** into which the **cytoplasm of the cell then flows.** These out-pushings are known as **pseudopods** ( ), or **rhizopods** ( ). Often there are several of these pseudopods thrust out at one time, although it is usually the one which comes in contact with some object which gains the mastery, all of the animal then rolling forward so that the cytoplasm extends into the out-pushing mentioned.

There have been various theories advanced to account for their movements (Fig. 45), they being as follows:

1. **The adherence theory.** This merely means that if a drop of water or any inorganic liquid be placed upon a flat surface, a part of it coming in contact with some other substance, the entire drop will gravitate toward the attached end. There are many pseudopods which are extended out into the surrounding liquid, however, and do not come in contact with any other solid substance; so, while this theory might explain those pseudopods which **do become attached, it does not explain those which are known as free** and which do not come in contact with solid objects.

2. **The surface tension theory.** This theory is also taken from the study of physics and chemistry and supposes that there are various currents which move **forward** or outward **in the central axis** and **backward along the surface.** Unfortunately for this theory, the currents in the amoeba do not run that way.

3. **The contractile theory.** This theory has had a varying history,

although apparently it holds the stage as well as any, and better than most theories at this particular moment. The current seems to start at the foremost part of the animal and extends backward. Jennings has shown that **Amoeba verrucosa** resembles an **elastic sac filled with fluid.** By placing this animal in a substance such as soot, which he caused to surround one of them, it was shown that the streaming followed the ectosarc toward the forepart of the animal, and just as it got beneath the **Amoeba,** remained there until the animal had moved over it, when it again moved upward at the posterior end.

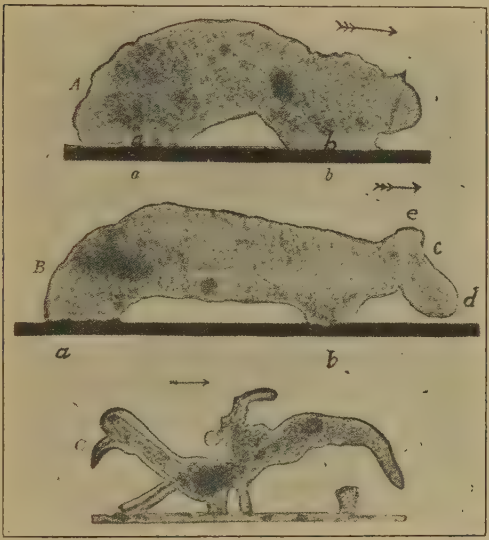

Fig. 45.—Locomotion of *Amoeba proteus.*

Photographs in side view. A and B show a specimen attached at two points, *a* and *b*, and a pseudopod which projects from one end and bends down to the substratum as in B at *d*; C shows the extension of a long pseudopod. (From Hegner after Dellinger.)

Dellinger has shown that whether on floor or ceiling, wherever **Amoebae** are found to move, there is a sort of creeping walk by which one or more outer parts of the animal are extended at random. When this projecting part comes in contact with a solid substance the most posterior attachment relinquishes its pseudopod. It is therefore assumed that there is a **contractile substance** within the animal.

All the various experiments that have been **performed** along this line have depended upon **surface tension** for their explanation. However, **even if the animal moves in a similar manner to a drop of liquid that is not living, it does not follow that it is the same force in each case that causes the movement.**

It is essential that all of the subject headings under which the frog was studied should also be borne in mind when the single-celled animals come in for investigation. For example, in regard to **metabolism** the following subjects must be studied just as in a more complex organism: **ingestion, digestion, egestion, absorption, circulation, assimilation, dissimilation, secretion, excretion,** and **respiration.**

It can readily be understood that there must be some **instinctive** process by which **Amoebae** know what food to ingest and what not to, or they might continue to take in sand particles and indigestible substances which would cause the body to become so extended and heavy that the animal would die from this effect alone. There are of course no organs such as a mouth and intestinal tract as there are in the frog.

The food is taken in **at any part** of the body. This food consists of tiny aquatic plants, other single-celled animals, bacteria, and various animal and vegetable matter.

It is of special interest to note that when food is taken by **Amoeba** the animal really places its body **around the food** (Fig. 46). Experiments with **inorganic substances,** such as a drop of chloroform in a watch glass of water have shown that the chloroform will take in substances like shellac and parraffine and reject wood, glass, etc. It must not be forgotten, however, that these substances which are thus accepted by the inorganic drop of liquid are those which **normally adhere to chloroform.** But with **Amoebae** the majority of food substances **do not adhere** to the surface of the animal, and so again there is considerable dissimilarity between the experiment and the actual facts in the case.

In digestion the food vacuoles have been embedded in the endoplasm. The cell wall pours out a secretion of some mineral acid supposedly HCl. This digestive fluid seems to dissolve only proteid substances and has no effects upon fats and carbohydrates. Hofer performed an interesting experiment by cutting an **Amoeba** in two parts after it had just been well fed and the part that did not have the nucleus was unable to digest food.

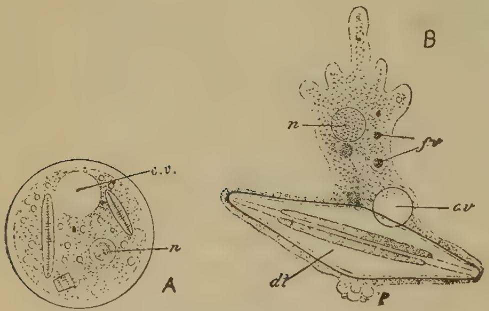

Fig. 46.

A, Amoeba encysted.

B, Amoeba ingesting a plant. *p*, retracted pseudopodium; *dt*, plant (diatom) taken in as food. *cv*, contractile vacuole; *f.v.*, food vacuole; *n*, nucleus. (After Leidy and Howes.)

A somewhat similar condition will be found a little later in the study of the **earthworm,** in which case, if the animal be cut in two behind certain segments the forepart of the animal, which contains the important organs, will **regenerate** a new tail. Whereas, the tail-part which has been cut off will **regenerate** another tail. This latter animal having **no organs,** must necessarily starve to death as it has no way of ingesting food.

After digestion has taken place in **Amoeba,** any indigestible particle may be thrown out at almost any point on the surface of the animal. These indigestible substances are probably heavier than the protoplasm itself, so this heavy portion sinks through the lower part of the animal body. Then as the animal moves away it leaves the indigestible solid particle behind.

There is **no circulatory system proper** in a one-celled animal, so that after the food has been digested it must be absorbed and passed into the body substance proper of the animal. Here we come to a new term.

that of **assimilation,** which means that now that new food matter has been digested and is within the body, there must be a rearrangement of some kind to form new particles and to add them to those already existing. It is this ability to **manufacture protoplasm from unorganized matter that is one of the very fundamental properties of living matter.**

Any movement or energy expended by an animal is due to the **breaking down of complex molecules** by what is known as **oxidation.*** The process of tearing down is called **katabolism** or **dissimilation.** This is a slow **combustion process** giving out heat and producing energy by which the animal can perform its various functions of life. The substance thus broken down and "used up" must also be accounted for in any scientific study. This **residual matter** usually consists of solids and fluids; namely, **water** and some **mineral substance, urea** and **carbon dioxide** (CO_2). Under this heading we include all **secretions, excretions, and products of respiration.**

Whenever glands produce a substance which is to be used again by the animal, such product is called a **secretion,** while substances which are thrown out of the body entirely are called **excretions.**

The **contractile vacuole,** by virtue of the fact of its containing **urea,** is considered an **excretory organ,** and because CO_2 also makes its way to the exterior of the organ, it is supposed to be **respiratory** likewise. **Amoeba,** like any animal, grows more rapidly than otherwise if food is plentiful. The food being taken internally the growth therefore comes from the center **outward,** in other words by **intussusception.**

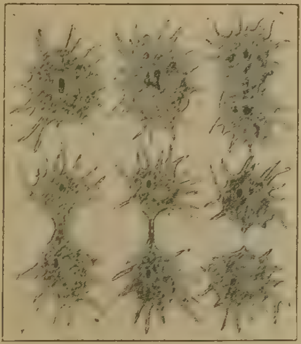

Fig. 47.

So-called amitotic division of Amoeba, showing the changes which take place during division. The dark body in each figure is the nucleus; the transparent circle, the contractile vacuole; the outer, clear portion of the body, the ectoplasm; the granular portion, the endoplasm; the granular masses, food vacuoles. Much magnified.

Whenever a cell reaches its full growth, its outer shell, membrane, or whatever its external covering may be called, not having infinite possibilities in the way of extension and stretching, usually breaks if more food is taken. **Cell division** is the process by which the plant or animal starts anew, thus saving the parent cell from breaking. A simple division into two (Fig. 47), is called **binary** or **amitotic** division. It will be remembered that this mere splitting in two parts is the shortest method by which cells divide, but, which, as we have already said, probably does not occur at all, and it is only due to our observational methods not being sufficiently delicate to note the **exact processes,** that we speak of amitotic division at all. In **Amoeba proteus,** however, which we are studying, there are two methods of division. The so-called **simple binary** or **amitotic,** just mentioned, and a process known as **sporulation.** There have been a few instances reported where the animal formed definite mitotic figures. Very few investigators have observed **sporulation.** "This latter process lasted from two and one-half to three months; the pseudopodia were first drawn in, and the animal became spherical. A three-layered **cyst** was then **secreted.** The **Amoeba** rotated within these for several days after which all movement ceased. The **nucleus divided** until there were twenty or thirty nuclei present, arranged near the surface. Continued division resulted in an increase of nuclei from five hundred to six hundred. Walls now appeared at the periphery, cutting off the nuclei, each with a small amount of cytoplasm. The wall of the cyst became soft, broken, and allowed the small amoeba to escape. Hundreds of these amaebulae or **pseudo-podiospores,** as they are sometimes called, broke out at one time. They became recognizable as **Amoeba proteus** in from two and one-half to three weeks. No reason could be discovered for sporulation, although experiments were conducted in which specimens were starved, were given an excess of food, were allowed to dessicate, and were transferred to water from different localities; none of these resulted in encystment and sporulation."

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*Oxidation may be likened to a series of infinitesimal explosions, which could be detected if we had instruments delicate enough for such a purpose.

However, whichever way the animal may divide it is simply a matter of growth before it is ready to divide again. We have here the interesting fact confronting us that these little single-celled animals are practically **immortal.** That is, **they do not die.** One may kill them by boiling and in other ways; but, left to themselves, they will continue until they have reached their limit of adultship when they divide, each individual becoming two new and separate animals.

It is important that the fact be grasped that in these little unicellular animals a parent **does not give birth** to its offspring. The **parent itself becomes the offspring.** That is, **there are no ancestors.** Each and every animal carries its complete and total ancestry with it.

BEHAVIOR

The way in which an animal reacts to a stimulus is called its **behavior**; and when that behavior has **not been learned,** but comes forth without consciousness on the part of the animal, yet is protective to the animal, such behavior or reaction is called **instinct.** In these lower one-celled animals two words are used in discussing behavior and instincts. These are **tropisms** or **taxis,** which merely mean a **movement of some kind.** To these words one adds the generic name of the stimulating cause, using the word **positive** and **negative** to explain one's meaning. For example, there are usually **eight tropisms** or **taxis** mentioned:

(1) **Thigmotropism,** meaning a **reaction to contact** of some kind;
(2) **Chemotropism,** meaning a **reaction to a chemical;**

(3) **Thermotropism**, meaning **a reaction to heat;**
(4) **Phototropism**, meaning a **reaction to light;**
(5) **Electrotropism**, meaning a **reaction to an electric current;**
(6) **Geotropism**, a **reaction to gravity;**
(7) **Chromotropism**, a **reaction to color;**
(8) **Rheotropism**, a **reaction to current.**

Amoebae move away from strong light, so that they are said to be **negatively phototropic.** They are also **negatively thigmotropic.**

If an action is self-imposed it is said to be **autogenous** ( ); if an external object causes a reaction, whether such object be located within or without the body, the action is known as **etiogenous** ( ).

EUGLENA

This little organism (Fig. 48) moves about like a full-fledged animal although it has chlorophyl in its body and manufactures its food as does the plant; and it does this notwithstanding the fact that it has a mouth and gullet.

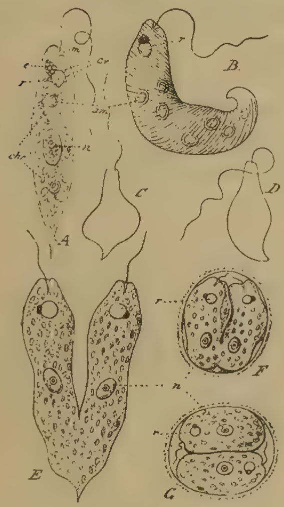

Fig. 48.
A. *Euglena viridis; m*, the so-called mouth; *n*, the nucleus; *e*, the stigma; *r*, reservoir; *c.v.*, contractile vacuoles; *chr*, chromatophors; *am*, pyrenoids with sheaths of paramylum. B, another specimen, showing change of shape and diagonal striation of the cuticle. C and D, outlines to show various stages of contraction. E, a free swimming specimen undergoing longitudinal division. F and G, division of an encysted form. (A-D, after Bourne; E-G, after Stein.)

Euglena belongs to the **Class Mastigophora** ( ), which means that there is a **whip-like flagellum** protruding from its **anterior end.** Several animals must be grouped together in order that the naked eye may see any organisms present. When there are many about there is a characteristic green color given the surrounding water.

EXTERNAL AND INTERNAL FEATURES

Euglena viridis is a single celled elongated animal pointed at the posterior, and blunt at the anterior end. As in **Amoeba**, there are two layers in the cytoplasm, the **ectosarc**, a dense outer layer, and the **endosarc**, a more fluid central mass. There is a thin **cuticle** running in parallel thickenings around the body of the animal in an oblique direction so that it appears striated.

The **mouth** is a funnel-shaped depression lying a little to one side of the center of the anterior blunt end. The **gullet** is a continuation of this depression. It looks like a duct, and connects with a large **spherical vesicle**, the **reservoir**, into which several minute **contractile vacuoles** discharge their contents.

There is also a red dot, called an **eye-spot** or **stigma,** close to the reservoir, near the inner end of the gullet. It is made up of small granules of **haematochrome** ( ). Because the anterior end of the animal seems to be more sensitive to light than other parts, it is supposed that this red stigma functions somewhat as an eye. It has also been suggested that this red haematochrome is not the sensitive part at all but that the protoplasm immediately beneath it is. As haematochrome has many of the characteristics of pigment granules of the eyes of higher animals, it is likely that we meet here with a sort of **beginning eye.**

There is a **single nucleus** a little posterior to the center of the body. It has a **distinct membrane.** On the inside of the nucleus there is a **so-called nucleolus.** However, as this latter functions as a **division center** it is probably not a nucleolus.

There are a number of oval discs called **chromatophores** ( ) suspended in the protoplasm. These contain **chlorophyl.** In **Euglena** we meet with our first example of **photosynthesis** ( ). A little later, when plant-life is studied, it will be noted that this is the accepted method among plants of manufacturing their food. Photosynthesis means that "the chlorophyl is able, **in the presence of light,** to break down the carbonic acid (CO_2), thus setting free the oxygen, and to unite the carbon with water, forming a substance allied to starch called **paramylum** ( ). If specimens are kept in good light continually a large amount of paramylum will be stored up for future use, being laid down around some granules of proteid substance near the center of the body. These granules are called **pyrenoids** ( ). Both the pyrenoids and chromatophores are permanent cell structures and increase in number by division and not by the origin of new ones from the other parts of the body."

LOCOMOTION

The animal moves by means of its **flagellum,** which appears as a single whiplike structure, although really it is composed of four separate fibrils wound together. This flagellum begins in the body proper and extends through the wall of the mouth depression. It is often as long as the animal itself. In addition to the assistance rendered the animal in locomotion by this appendage, the entire animal is elastic, contracting and expanding, so that the body looks much like a worm in movement.

NUTRITION

As already stated, **Euglena** is like a plant in that it possesses chlorophyl and manufactures its own food. When an animal manufactures its food in this way it is said to be **holophytic** ( ). But as **Euglena** can live in the dark, and chlorophyl does not permit the manufacture of food without light, the animal must be able to feed in some other way also When organic substance in solution is taken in through the body wall, as probably happens in the case of **Euglena** when in the dark, such method of obtaining food is said to be **saprophytic** ( ), while those animals which ingest **solid particles of food** like the frog are said to be **holozoic** ( ).

ENCYSTMENT

Euglena, like **Amoeba,** when food becomes scarce, as well as for unknown reasons, may encyst. It does this by becoming spherical, secreting a rather thick gelatinous covering, and throwing off the flagellum.

REPRODUCTION

This takes place by **binary longitudinal division.** "The nucleus divides by a primitive sort of mitosis. The body begins to divide at the anterior end. The old flagellum is retained by one-half, while a new flagellum is developed by the other. Often division takes place while the animals are in an encysted condition. One cyst usually produces two Euglenae, although these may divide while still within the old cyst wall, making four in all, while recent observers have recorded as many as thirty-one young flagellated Euglenae which escaped from a single cyst."

BEHAVIOR

Euglena swims in a spiral manner as does the paramoecium. Like the paramoecium, too, it has only two reactions to stimuli. But in the case of **Euglena,** the forepart of the animal swings about in a circle while the posterior part remains more or less stationary, thus forming a sort of pivot around which the forepart moves.

It is **positively phototropic** though direct sunlight will kill it. As all plants and animals need certain quantities of air, moisture and heat, in which they thrive best, being injuriously affected if too much of these substances is applied, the phototropic action, as well as the killing by an overabundance of light, is understood. The environmental conditions in which an organism thrives best is called the **optimum** ( ) for such organism.

VOLVOX

All the unicellular animals having whip-like flagella come under a sub-grouping known as **Mastigophora.** This group is particularly interesting in that it furnishes us with our first example of unicellular animals forming **colonies.** The best known and studied of this group of **colonial flagellata** is **Volvox** (Fig. 49) found in fresh water ponds. Doflei found as many as twenty-two thousand cells in a single colony. There is a **division of labor** in the colonies, for the various cells are not all alike, though each is a separate and distinct animal. Some of these cells are **somatic** and nutritive, while others are **germ-cells** or reproductive. Here also we come in contact with our first and lowest form of **sex life.** Any organ which produces sex cells is known as a **gonad.** There are certain germ cells in a colony of volvox called **parthenogonadia** (   ). These divide into many cells which drop into the center of the mother colony and finally escape through a break in the wall. There are **other** germ cells, however, which are also produced; the smaller are called **spermatazoa** or **microgametes.** These are the **male germ cells,** while the **larger ones** called **macrogametes** or **eggs** are the **female germ cells.** The **eggs are fertilized** by the spermatazoa, and, after passing through a **resting stage,** develop into new colonies.

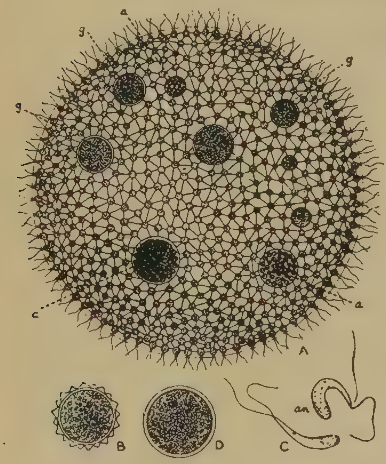

Fig. 49. Volvox.

The individual cells are united by radiating strands of protoplasm. A, a mature colony; *a*, spermaries; *g*, ovaries. B, zygote resulting from the fusion of the gametes. C, two sperm. D, egg. (From West, after Klein.)

Colonies may be of one sex only. In such cases the male colonies can be recognized by the sperm pockets arranged in a wide belt around the middle of the colony with the poles free from cells.

There is a distinct difference in a colony of single-celled animals of this kind and a **tissue** which is a sheet of similar functioning cells; such sheet being combined with others to form an organ while the organs form a complete single individual. In **Volvox** there is no such grouping of sheets of similar functioning cells. **Each cell is complete and distinct in itself** and is as much an individual as **Amoeba** or **Euglena** just studied, except that it is attached to its fellows.

PLASMODIUM MALARIAE

The malarial organism, **Plasmodium malariae** (Fig. 50), a member of the class **Sporozoa,** nearly all of which are parasitic, lives in the human body. Human blood contains minute circular disks known as red blood corpuscles, within which the malarial organisms may be found in persons who are suffering from **malaria,** or **chills and fever.** The organism first appears as an extremely minute body, in shape somewhat like the **Amoeba,** though much smaller. It increases in size. After reaching a size which nearly fills up the red blood corpuscles, it breaks up into twelve to sixteen small spores. The blood corpuscles now break into pieces and the spores are liberated into the liquid blood. Each may then make its way into a corpuscle and repeat again the history as already described.

All of the following details of the life-cycle of **Plasmodium malariae** must be thoroughly understood and memorized by the student, because, (1) **Plasmodium malariae** is the classic example of an animal-parasite

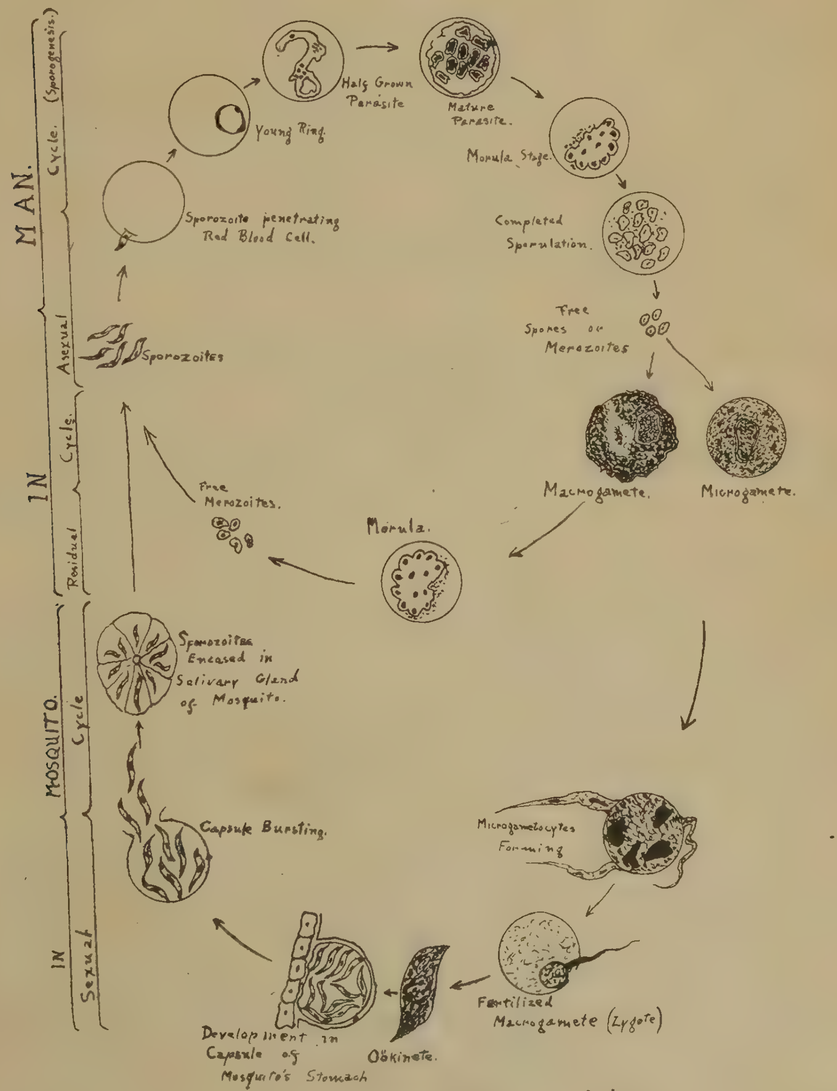

Fig. 50. Life Cycle of Plasmodium Malariae.

of tremendous importance to man; (2) it is our best known example of a parasite which requires an **intermediate host** before being able to carry infection; (3) it presents an excellent illustration of the methods used in obtaining experimental proof for scientific theories, and (4) it brings home an understanding of the vast quantity of painstaking effort necessary to obtain that proof.

The malarial organism, **Plasmodium malariae,** is a member of the class **Sporozoa,** nearly all of which are parasitic. It lives in the red corpuscles (therefore called **Haematozoa**) of human blood where it grows for a time, and then breaks up into from twelve to sixteen spores which rupture the corpuscle. The corpuscle itself then breaks up into tiny particles and the spores are thrown into the blood-stream.

The malarial parasite has two **life-cycles** (Fig. 50), so to speak, one the **sexual cycle,** which develops in mosquitos, and the other the **asexual cycle,** which develops in man.

1. The **sexual development** of the malarial parasite within the body of the mosquito takes from eight to ten days. These sexual forms are known as **gametes.**

The male cell **(gamete)** is also called a **gametocyte.** This gametocyte develops from four to eight **microgametes** which force their way into the large female cells **(macrogametes).**

A sort of fertilization is thus set up. This fertilized cell is now called a **migrating cell** or **oökinete.** The oökinete penetrates the stomach-wall of a mosquito and builds a cyst **(oöcyst).** Grassi says there may be as many as five hundred oöcysts at a time in the stomach-wall of a single mosquito.

In the oöcyst many tiny spherical bodies develop. **(sporulation.)** These spherical bodies are the **sporoblasts** (primitive spore-cells) which develop into thousands of **sporozoites.** These latter are merely tiny filaments which get into the lymph system of the entire body of the mosquito. As they reach the mouth-parts they are ready to be injected into any human being which the mosquito bites. Once inside man, they enter the red-blood corpuscles and are known as **schizonts** (asexual forms).

From here on we must trace the asexual cycle of development in man. The injected organism which has been placed in the blood-stream of man is called **sporozoite.** It finds its way into the red blood corpuscles and becomes rounded and more or less ring-shaped while it is amoeboid in movement. It is now a full fledged **schizont** ( ). The schizont lives at the expense of the red corpuscle and deposits scattered black or reddish, so-called **melanin** granules. These granules should properly be called **haematozoin granules** ( ).

The schizont now matures and becomes rosette-shaped when it is known as the **morula.** Its nucleus breaks into daughter nuclei, or rounded spores, known as **merozoites** ( ), the number of which may vary from six (in the Quartan fever parasite), to twenty (in Tertian fever type).

The red corpuscle is finally broken up. This liberates the merozoites into the blood-stream where (within an hour) they may again attack and enter other red blood cells.

The breaking up of the red blood cells takes place at the moment the merozoite is mature, and the chills and fever likewise appear at this time.

It will be readily understood that when thousands of red corpuscles are thus removed from the circulation, the patient will be pale **(anaemic)**. The chills may be due to the haematozoin granules, which possibly contain poisonous substances.

This process of the merozoites being thrown out of the red corpuscles into the blood-stream may continue for some time, but after a while, rounded forms, which throw off tiny filaments, appear. These are the male sexual forms which require a mosquito as host before being able to develop further. The female forms may, however, either go on developing in man or remain dormant, and come forth again at some later date when conditions are favorable. The sexual cycle, already described in the mosquito's body, now begins if the infected individual is bitten by a female **Anopheles** mosquito.

The chills always appear at regular intervals, because the **incubation period** of each of the three kinds of malarial parasites (although differing for each species) is always the same for the same species. Thus the tertian fever species **(Plasmodium vivax)** "hatches" every third day—hence its name; the quartan **(Plasmodium malariae)** every fourth day, while the aestivo-autumnal type **(Plasmodium immaculatum Laverania)**, at irregular intervals. In fact, the physician uses this definite incubation period as his clue in diagnosing the case, to find what particular type of malarial parasite has infected his patient.

After the spores or merozoites are thrown into the blood-stream, many are devoured by the white corpuscles **(leukocytes)**, but those not devoured, again enter new red corpuscles and so continue reinfecting the same patient, although they are unable to infect another.

The method of **communication** from one person to another can only come about in the following manner:

A female mosquito of the genus **Anopheles** must suck the blood of an infected person if the disease is to be communicated. As soon as the infected blood reaches the changed environment of the mosquito's stomach, the series of changes begin in the merozoites, which have been described above. It will thus be seen that **Plasmodium malariae** must not only pass through two stages of a life-cycle, **sexual** and **asexual**, but these two stages are unable to develop in a single host, the asexual stage developing in man, and the sexual in mosquitos.

At this point the question will occur, "How do we know all this?" It is the answer to this question which will give the student (1) the finest illustration of what modern laboratory methods mean; (2) it will acquaint him with the exhaustive investigations which students of science are always performing, and (3) it will show him what great quantities of material must be sifted before one can prove an accepted scientific theory, or advance a new one.

It was on November 6, 1880, that Dr. Laveran, a French army surgeon serving in Algeria, plainly saw the living parasites under the microscope in the blood of a malarial patient. But it was not until five years later that medical men accepted his findings. Then several Italian pathologists, prominent among them being Golgi, Marchiafava, and Celli, worked out the behavior of the parasite in human blood. These men found that the fever and chills always came at definite periods of development in the parasite.

But they could not find how the parasite got into the blood of the patient. The name "Malaria" is Italian and means "bad-air" (malaria) and the disease had always been associated with swamps and stagnant water, so it is not strange that mosquitos had been thought of as having some relationship to the disease. Medical men were, however, inclined to consider such a thought as savoring too much of superstition to consider it.

Notwithstanding this general attitude, Dr. A. F. A. King, an American physician, in 1883 summed up the evidence which to him seemed quite conclusive for such an association.

Riley and Johannsen have put Dr. King's argument in the following words:

1. Malaria, like mosquitoes, affects by preference low and moist localities, such as swamps, fens, jungles, marshes, etc.

2. Malaria is hardly ever developed at a lower temperature than sixty degrees Fahr., and such a temperature is necessary for the development of the mosquito.

3. Mosquitoes, like malaria, may both accumulate in and be obstructed by forests lying in the course of winds blowing from malarious localities.

4. By atmospheric currents malaria and mosquitoes are alike capable of being transported for considerable distances.

5. Malaria may be developed in previously healthy places by turning up the soil, as in making excavations for the foundation of houses, tracks for railroads, and beds for canals, because these operations afford breeding places for mosquitoes.

6. In proportion as countries, previously malarious, are cleaned up and thickly settled, periodical fevers disappear, because swamps and pools are drained so that the mosquito cannot readily find a place suitable to deposit her eggs.

7. Malaria is most dangerous when the sun is down and the danger of exposure after sunset is greatly increased by the person exposed sleeping in the night air. Both facts are readily explicable by the mosquito malaria theory.

8. In malarial districts the use of fire, both indoors and to those who sleep out, affords a comparative security against malaria, because of the destruction of mosquitoes.

9. It is claimed that the air of cities in some way renders the poison innocuous, for, though a malarial disease may be raging outside, it does not penetrate far into the interior. We may easily conceive that mosquitoes, while invading cities during their nocturnal pilgrimages, will be so far arrested by walls and houses, as well as attracted by lights in the suburbs, that many of them will in this way be prevented from penetrating "far into the interior."

10. Malarial diseases and likewise mosquitoes are most prevalent toward the latter part of the summer and in the autumn.

11. Various writers have maintained that malaria is arrested by canvas curtains, gauze veils and mosquito nets, and have recommended the use of mosquito curtains, "through which malaria can seldom or never pass." It can hardly be conceived that these intercept marsh-air but they certainly do protect from mosquitoes.

12. Malaria spares no age, but it affects infants much less frequently than adults, because young infants are usually carefully housed and protected from mosquito inoculation.

King's work does not seem to have come under the notice of the European and Asiatic workers, so it was not until 1894 that Sir Patrick Manson, who had done pioneer work in filariasis (See Chapter XX), came to the conclusion that there must be an intermediate host for a parasite so similar in its general functioning as malaria is to filaria.

It was already known that long thread-like processes formed as soon as the parasite escaped from the blood, and became free-swimming in the surrounding media.

At first it was thought that water containing the parasite was the carrier of infection but no one who drank the water developed malaria; in fact, they did not even develop the disease when this water was actually injected into the veins.

Manson then suggested that these motile forms must have something to do with the manner of communicating the disease, and it was he who also thought a blood-sucking insect the most likely intermediate host. After so much progress had been made it was a simple matter to think of the old association of mosquitoes and malaria.

It is interesting to note also, that Laveran working independently, come to similar conclusions in the same year that Manson did.

Major Ronald Ross, in India, without any knowledge of the form or appearance of the parasite during the time it is developing within its intermediate host, and without a knowledge of the species of the insect he was looking for, spent two and a half years of intensely arduous work following out experiments largely suggested by Manson.

Finally, in August, 1897, seventeen years after the parasite was first discovered in man, he obtained his first clue.

While he was dissecting a "dappled-winged" mosquito and had searched every cell and found nothing, he came to the insect's stomach. In writing of this, Major Ross says: "Here, however, just as I was about to abandon the examination, I saw a very delicate circular cell, apparently lying amongst the ordinary cells of the organ and scarcely distinguishable from them. On looking further, another and another similar object presented itself. I now focused the lens carefully on one of these, and found that it contained a few minute granules of some black substance, exactly like the pigment of the parasite of malaria. I counted altogether twelve of these cells in the insect."

As he searched further he found the mature pigment cells contained multitudes of thread-like bodies which, when the parent cell was ruptured, poured into the body of the insect. These were the spores formed in the sexual generation.

Major Ross did his experimental work on birds which are infected with malaria, but his results were soon found to apply to man as well.

So complicated a scheme of things can never appeal to men at large, and yet it is just men at large who must assist in any preventive measures which are to wipe out diseases of this nature. For this reason a series of popular experiments were tried out.

Drs. Sambon and Low, of the London School of Tropical Medicine, went to the most malarial portion of Rome in the most dangerous season. Here they lived with three or four others from July until the 19th of October in a specially constructed mosquito-proof hut near Ostia. They were thus protected from sunset to sunrise from the bites of mosquitoes. Not one of them became infected, while mosquitoes sent from here to London were allowed to bite several people (Dr. Manson's own son being one of the subjects who volunteered for the experiment), all of whom came down with the disease.

Again, in Italy, railroad employees who were housed in mosquito-proof huts did not develop the disease while those not so housed did.

Our own experience in cleaning up the Panama Canal Zone of Malaria and Yellow Fever are notable examples of preventive measures being used most effectively, from the knowledge gained in the study of the life-cycle of the malarial parasite.

In Cuba, Yellow fever (also a disease caused by an infecting parasite carried by the mosquito), was shown, likewise, to be carried only through an intermediate host. Major Walter Reed had workmen sleep in beds and use the clothing of those who died of yellow fever, but kept such men housed in mosquito-proof huts, and not one developed the disease, while those who were bitten by the infecting mosquito and having perfectly clean bedding and linen took the disease. Dr. Charles J. Finlay of Havana, Cuba, and Major Walter Reed are the Manson and Ross of the Yellow-fever parasite.

There are a hundred and twenty-five species of mosquitoes in North America, but it is only the female of the genus **Anopheles** which can transmit malaria to man, though some members of the genus **Culex** do transmit it to birds. (At least this is true in India.)

The distinguishing characteristics of the two groups is as follows (Fig. 51): In **Culex** the wings are clear, while in **Anopheles** they have brown spots. In **Culex** the axis of the body forms a curved line as though the insect were hump-backed, while **Anopheles** presents a straight line when resting. For those familiar with insect anatomy we may add that **Culex** has short maxillary palpi while **Anopheles** has them almost as long as its proboscis; and lastly, for those with a musical ear, we may add that the female **Anopheles**, which is the only one which carries the malarial parasite, sings several tones lower than the **Culex**.

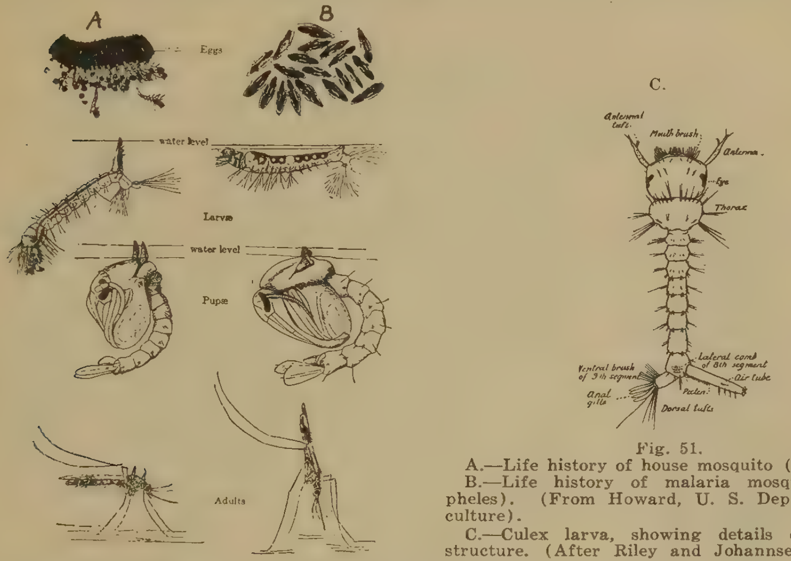

Fig. 51.
A.—Life history of house mosquito (Culex).
B.—Life history of malaria mosquito (Anopheles). (From Howard, U. S. Dept. of Agriculture).
C.—Culex larva, showing details of external structure. (After Riley and Johannsen.)

The eggs of **Culex** are always laid in a mass, while those of **Anopheles** are laid singly. As the eggs hatch, the larvae of **Culex** hang from the surface of the water at about an angle of 45 degrees, while the larvae of **Anopheles** lie almost parallel to the surface of the water.

Prevention is always the scientific method of overcoming disease. Because mosquitoes lay their eggs in quiet pools, men conceived the idea of preventing these eggs from hatching. This has not been possible, but oil poured on the water will kill the little wrigglers after they hatch.

The breathing tubes of wrigglers are provided with **hydrofuge plates** at their openings which will not permit water to enter. Since these hydrofuge surfaces are due to the presence of oil, it is obvious that oil poured on the surface of the water will mix with this and cause the entry of oil into the breathing tubes, thus asphyxiating the wrigglers. It has been thought that certain kinds of fish destroy eggs and wrigglers. Muttkowski personally examined over 6,000 of these fish-stomachs and found only one mosquito wriggler. Another observer examined about 2,000 specimens of **Gambusa,** the so-called "mosquito-destroying top minnow," and found mosquito wrigglers in only about 2% of the fish.

PARAMOECIUM

The animal now to be studied is the **Paramoecium** (Fig. 52), a member of the **class Infusoria.*** Paramoecia are often called slipper animalculae because they are shaped like a slipper, or more correctly like a cigar. The **distinctive characteristic** of this animal is that its entire body is covered with **little hair-like projections called cilia.** The rapid movement back and forth of these cilia (especially those of the oral groove which beat faster than those on other parts of the body), causes the animal to be propelled through the water in which it swims. There is an **oral groove** extending **obliquely backward** from the forward end which empties just a little behind the middle portion of the body. The mouth is situated at the end of the oral groove, so that as the animal is swimming along and constantly revolving, various substances are forced down the oral groove and as they reach the end of this groove are thrust into the mouth proper. There is also an endosarc and ectosarc just as there is in **Amoeba,** but there is also an additional membrane or **pellicle,** sometimes called the **cuticle.** This is demonstrated by placing a drop or two of 35% alcohol in a drop of water where some of the **Paramoecia** are found. The pellicle will then be raised like a blister, showing that this part is separate and distinct from the rest of the animal. Immediately beneath the cuticle there is found a layer of spindle-shaped cavities in the ectoplasm filled with a semi-fluid substance. These are known as **trichocysts** (   ), supposed to be weapons of offense and defense (Fig. 53). If a little acetic acid or even ordinary blue or green fountain pen ink is added to the water these trichocysts are exploded, and the long threads which they contain are discharged.

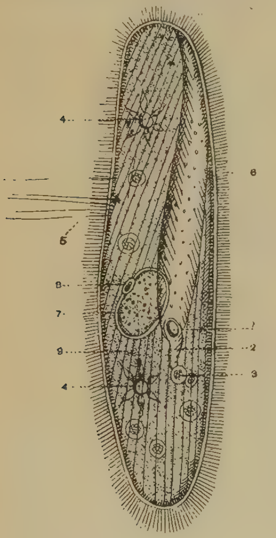

Fig. 52.
Paramœcium caudatum.
1. Mouth at bottom of groove. 2. Oesophagus. 3. Food vacuole just being formed. 4. Contractile vacuoles. 5. Trichocysts which have exploded; the unexploded ones line the cuticle. 6. Cilia. 7. Meganucleus. 8. Micronucleus. 9. Contractile fibrils. (After Bütschli.)

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*The early workers in biology took vegetable matter, such as dried grass, and steeped it in boiling water, then letting this infusion stand in the air. The animals found therein were called *Infusoria.*

There are two **contractile vacuoles,** one close to each end of the body, while six to ten radiating canals communicate with these vacuoles and other portions of the body. These canals collect the fluid from the surrounding protoplasm and pour it into the vacuoles, after which the **vacuoles contract alternatively** at intervals of twenty seconds and discharge their contents to the outside of the body.

This, it will be remembered, is as it is in **Amoeba,** where the contractile vacuoles act as organs of both excretion and respiration. **Paramoecia** feed on **bacteria** and **minute unicellular animals.** The animal moves back and forth rapidly, causing a current of water to be sent down the gullet so that various food particles are swept in. Along the gullet there is a row of cilia which have **fused together** forming what is called an **undulating membrane.** As the food enters the end of the gullet a food vacuole is produced, which as soon as fully formed, separates from the gullet and is swept away by the **rotary streaming movement** of the endoplasm. This process is known as **cyclosis** ( ). The **digestion occurs within the food vacuole,** while the undigested particles are cast out at a definite **anal spot** which can only be seen when these particles are discharged.

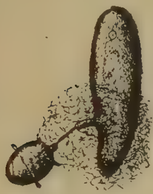


Fig. 53.
Paramœcium defending itself from an attack by a Protozoon, *Didinium.* The triochysts are discharged and mechanically force the enemy away. (From Hegner, after Mast.)

BEHAVIOR

Conjugation and division of **Paramoecia** will be discussed in the following chapter. Here the ordinary reactions of this animal will be taken up.

While **Paramoecia** normally swim by means of cilia, they can, when forced to, exhibit great elasticity and pass through very small openings. The body goes forward, turning round and round on its long axis, always **toward the left** as it is propelled forward. This is the result of the cilia in the oral groove growing more rapidly and effectively than elsewhere, so that one obtains approximately the same effect as rowing in a boat in which the oars on one side are applied much more strongly than on the other. The animal would naturally swim in a circle if this were the only force applied, but as **it rotates** on its long axis continually, it goes forward. This produces a spiral course. "The swerving, when the oral side is to the left, is to the right; when the oral side is above, the body swerves downward; when the oral side is to the right, the body swerves to the left, etc. Hence the swerving in any given direction is compensated by an equal swerving in the opposite direction; the resultant is a spiral path having a straight axis."

Paramoecium responds to stimuli negatively and positively just as do other forms of unicellular animals. This animal has been particularly well studied in the laboratory as to its reactions to various stimuli.

and it is intensely interesting to note that whenever any injurious substance or stimulus is applied at its anterior end, the **cilia reverse themselves** and the animal **swims backward** for a short distance away from the reason of stimulation. The forepart of the animal then swings about, using the posterior part as a pivot, when the animal again moves forward. If it again comes into an undesirable medium, the same process is repeated. As the animal backs up from an unpleasant stimulus, using its posterior end as the pivot upon which to turn, various samples of the surrounding medium are brought into the oral groove, so that, as soon as these samples of liquid no longer contain the unpleasant stimulus, the animal moves forward.

The important point to remember here is that **Paramoecium has only two reactions,** the **going forward** and the **going backward.** Much erroneous interpretation may be avoided if this be remembered when the study of the **animal mind,** or **animal psychology,** is taken up later; for, no matter how many hundreds of times an animal of this kind may try an experiment, it always continues this **trial and error method** of going forward, bumping into something that is antagonistic to itself, backing up, and again coming forward until it **accidentally** gets into a medium that is satisfactory. In fact, there are some substances, such as acetic acid, to which **Paramoecia** react in a peculiar manner. If a drop of this acid be placed before the animal, it will enter the liquid; but once within the acid-drop it will react to the surrounding water in a negative manner; that is, it will come to the edge of the acid-drop and then back away again and again. Then, the trial and error **method** may be observed when heat is applied to the surrounding media. The animal tries almost every direction until it finds some method of escaping from the unfavorable stimulation, **the optimum temperature** is normally between 24 and 28 degrees C.

There are positive reactions of **Paramoecium** also, such for example as its habit of lying against solid objects. **Paramoecia** are **negatively geotropic,** in that they usually come toward the upper portion of the water in which they are placed. The animals usually swim upstream and it is supposed that the reason for this is that the current might interfere with the beating of the cilia if another direction were taken.

It is generally supposed that it is the physiological condition of **Paramoecium** which determines the character of any response to a given stimulus. This means merely that the actions are more or less **spontaneous** and **due to the internal condition of the animal (autogenous).** This internal condition changes, however, with the **different amounts and qualities of food and digestion.** "Thus one physiological state resolves itself into another. This 'becomes easier and more rapid after it has taken place a number of times,' giving us grounds for the belief that stimuli and reaction have a distinct effect upon succeeding responses."

"We may sum up the external factors that produce or determine reactions as follows:

1. The organisms may react to a change even though neither beneficial nor injurious.

2. Anything that tends to interfere with the normal current of life activities produces reactions of a certain sort (negative).

3. Any change that tends to restore or save the normal life processes may produce reactions of a different sort (positive).

4. Changes that in themselves neither interfere with nor assist the normal stream of life processes may produce negative or positive reactions, according as they are usually followed by changes that are injurious or beneficial.

5. Whether a given change shall produce a reaction or not often depends upon the completeness or incompleteness of the performance of the metabolic processes of the organism under the existing conditions. This makes the behavior fundamentally regulatory."

When one organism causes disease in another it is said to be **pathogenic** to the organism affected. For example, **Amoebae bucallis** are found in **pyorrhea,** a disease of the teeth. The drug **emetine** kills **Amoebae bucallis** and when these are killed the diseased condition improves. From these facts it has been concluded that this particular protozoan is the cause of pyorrhea, although this is not strictly true.

While, as we shall shortly see, most of the pathogenic organisms belong to the **plant kingdom**, still the following animal organisms which cause disease in man, are rather important factors in the study of biology:

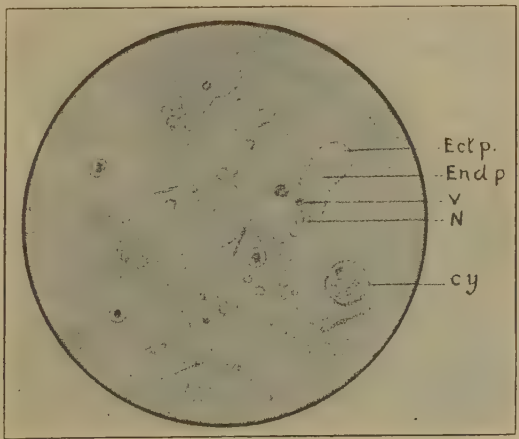


Fig. 54.

Entamoeba histolytica from a case of amoebic dysentery in man. *Ectp.*, ectoplasm; *Endp.*, endoplasm; *V*, vacuoles; *N*, nucleus. *cy*, encysted amoebae. (After Rivas).

PATHOGENIC PROTOZOA

Class I. Rhizopoda

(a) **Entamoeba hystolytica** (also called entamoeba dysenteriae (Fig. 54).

Entamoeba histolytica causes a chronic ulcerative process in the large intestine, so-called amoebic dysentery. The organisms are frequently carried to the liver by the portal circulation and give rise to abscesses which may attain a large size and may extend to a pleural cavity or to a lung.

It is a common infection in the tropics, but occurs also more or less frequently in temperate zones.

The organism measures fifteen to twenty-five micra in diameter. It contains a small round vesicular nucleus which stains but poorly with the ordinary basic dyes and with alum hematoxylin. The nucleus contains a minute nucleolus. The cytoplasm around the nucleus is finely granular and is surrounded by an outer zone or ectosarc which is transparent and refractive, and which sharply defines the outer limits of the organism.

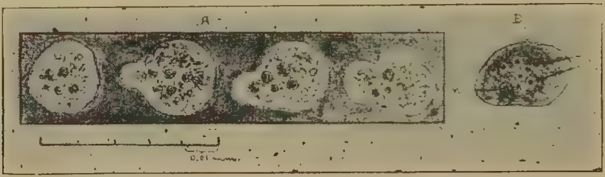


Fig. 55.

Entamoeba gingivalis (*buccalis*). (After A. J. Smith in Dental Cosmos, Sept., 1914).

The entamoeba hystolytica is examined on a warm stage, in order to detect the characteristic movements; but it is readily identified in properly fixed tissues owing to its characteristic morphology.

"The organism is quite **phagocytic** and frequently contains red blood corpuscles, bacteria, or cellular debris. It is able to penetrate fibrous and other tissues and is frequently found in the walls of blood vessels and inside of them."

It secretes a mild **toxin** (which may be a waste product) which slowly kills the cells in its neighborhood and then gradually dissolves them.

Amoebae are, however, often found in normal tissues. Sometimes the nuclei seem to be fading out.

It is found principally in the intestines and sometimes in the liver.

Cultures of these amoebae have been shown to withstand drying from eleven to fifteen months.

(b) **Entamoeba buccallis** (also called **E. gingivalis** and **E. den-**

talis) has been said to cause pyorrhea alveolaris (Fig. 55), but Rivas holds that these **Amoebae** are the effect of infection and thus represent a secondary infection which aggravates the primary infection.

Class II. Sporozoa

Subclass 1. Telosporidia ( )

Order 3. Haemosporidia ( )

Plasmodium which causes malaria. (See Fig. 50.)

Subclass 2. Neosporidia ( )

Order 2. Sarcosporidia ( )

Sarcocystis miescheriana. (Fig. 56.)

Medical men often call these organisms "Rainey's tubes." They are found in the muscles of pigs.

These tubes are ovoid bodies filled with small sickle-shaped unicellular organisms—the **sarcocystis miescheri.** It sometimes is found in man, causing serious disease called **psorospermiasis,** usually fatal.

Class III. Mastigophora

Order 1. Flagellata

Trypanosoma gambiense (Fig. 57) causes the disease known as **trypanosomiasis,** commonly known as **sleeping sickness.**

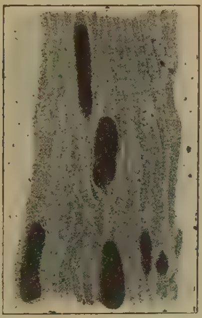


Fig. 56.
Longitudinal section through muscle of a Pig, containing *Sarcocystis Miescheriana* (Kühn). (After Braun.)

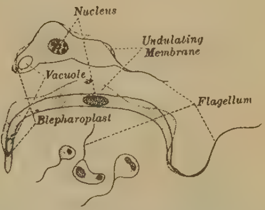


Fig. 57.
Trypanosoma gambiense, from a case of sleeping sickness. Different forms. (After Manson.)

These parasites are found in many invertebrates and vertebrates.

Life history in **two** stages. **One "a flagellate monadine** ( ) phase, in which they live in the blood-stream of vertebrates, and in some of which they cause serious disease; the other is a **gregarine** ( ) **non-flagellate** phase which may also **be parasitic** and which is met with in forms of Kala-Azar."

Causes **sleeping sickness,** which is common in West Africa. Those living on "wooded shores of lakes and rivers, such as fishermen and canoe men are subject to it. The parasite is carried "by the bite of the **tsetse fly (glossina palpalis)**, and where this insect exists the disease is liable to prevail. The fly lives on the bushes on the lake shores or river banks, and feeds on the blood of crocodiles, antelopes, etc. The trypanosomes undergo changes in the body of the fly and the infectivity does not appear until the thirty-second day, but continues for at least seventy-five days."

The parasite is found mostly in the **cerebro-spinal fluid,** though less commonly in the blood. Hope of exterminating the disease seems to lie in exterminating the game (crocodiles especially) on which the tsetse fly feeds.

FLAGELLATES OF UNCERTAIN POSITION. (Fig. 58.)

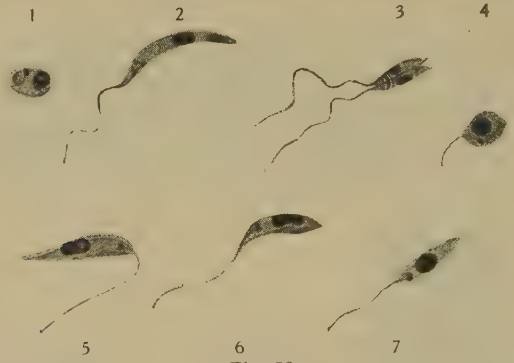


Fig. 58.

Kala-Azar organism. *1,* from a patient in India; *2* and *3,* individual flagellate, (*Leishmania Jonovani*); *4, 5, 6* and *7, Leishmania infantum.* (From Kolle-Wassermann).

Leishmania donovani.
Leishmania infantum.
Leishmania tropica.

Causes **Indian Kala Azar** (dum-dum fever), **Infantile Kala Azar,** and **tropical boil,** respectively. Common in Asia. Causes lesions on exposed surfaces of body and enlarged spleen and anaemia.

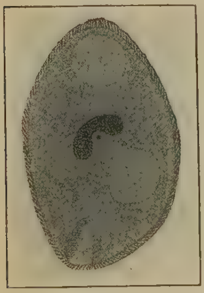


Fig. 59.
Balantidium coli, from an ulcer of man's intestine. After Braun and Lühe.)

The bed-bug or a blood-sucking bug is probably the common carrier because ingested parasites undergoing development into flagellate forms have been found in the bed-bug.

The infantile disease affects **children only; probably through dog fleas,** as dogs are **spontaneously infected in the epidemic regions.**

Class IV. Infusoria

Balantidium coli (or Entamoeba coli). (Fig. 59.)

A ciliated, oval-shaped infusorian. There is a "bean-shaped macro-nucleus and a spherical micro-nucleus. In tissues the organisms frequently exhibit changes in form due to ameboid motion, as in penetrating the epithelial lining of the intestinal glands.

"The organism is a common inhabitant of the intestine of the hog where it causes no lesion. On rare occasions it is apparently transferred to man and gives rise to more or less extensive ulcerations in the large intestine (rarely in the lower end of the small intestine) accompanied by persistent diarrhea which may terminate fatally."

They are found in the lumen and walls of the intestine but usually they penetrate the epithelial wall and lie next to a gland. Some collect in the lymph-nodules while often they are found in lymph-vessels and veins, but they do not seem to be distributed by streams of these vessels. They have been found in the liver.

They do not seem to produce a toxin but **do a mechanical injury only,** although this injury **opens paths through which bacteria often cause infections.**

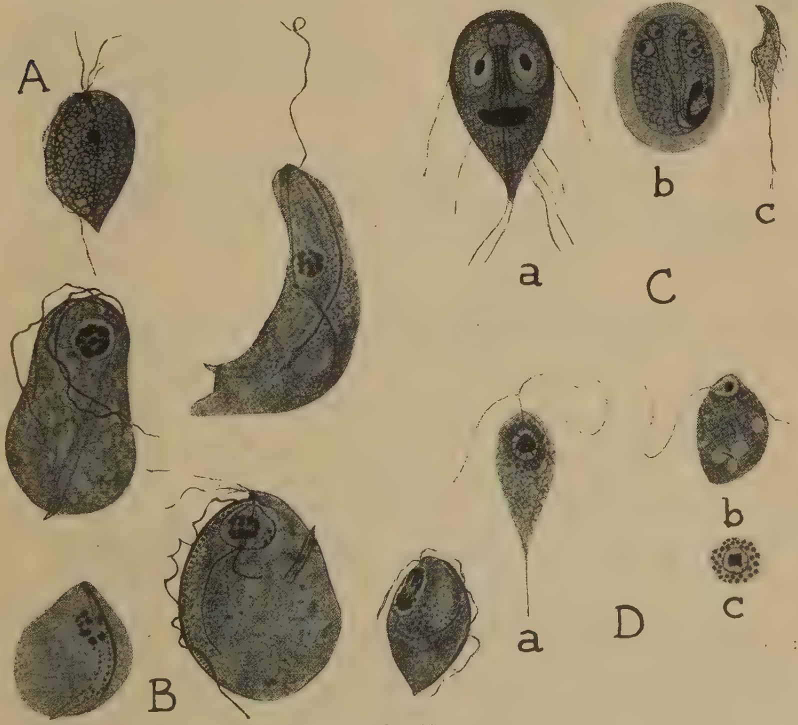


Fig. 60.

A. Partially schematic drawing of *Trichomonas intestinalis.*
B. *Trichomonas muris* dividing (5 stages).
C. *Lamblia intestinalis. a,* flagellated form; *b,* cyst; *c,* flagellated form viewed from the side.
D. *Cercomonas hominis. a* and *b,* show different forms of the organism; *c,* cyst.
(From Kolle-Wassermann; B, after von Kuczynski; C, after Benson and Grassi and Schewiakoff; D, after Wenyon.)

The ulcers caused by this organism resemble those caused by entamoeba histolytica.

Trichomonas hominis (Fig 60).

Cercomonas hominis

In intestines, causing acute or chronic diarrhea.

Lamblia intestinalis

Larger than the trichomonas. Flagellated forms have been found in the sputum of cases of gangrene of lung, and in those having pleurisy.

Spirochaeta recurrentis (Fig. 61).

Causes **Relapsing Fever** (also called **Famine Fever, Seven Day Fever, and Tick Fever),** probably transmitted by mosquitoes or bugs. From five to seven relapses take place after all symptoms have disappeared.

The spirillum or spirochete is 15 to 40 micra long, shaped like a corkscrew. Quite motile and present in blood during the febrile paroxysms, disappearing at intervals.

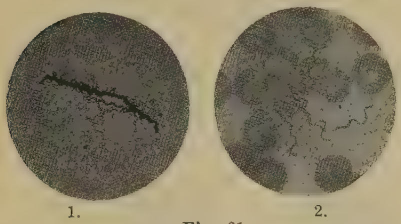


Fig. 61.
1. *Spirochaete recurrentis,* found in Russia.
2. Same as 1, but from a patient in Africa.
(From Kolle-Wassermann).

"The disease has been reproduced by injecting into a healthy monkey blood sucked by a bug from the infected animal."

Treponema Pallidum (Fig. 62).

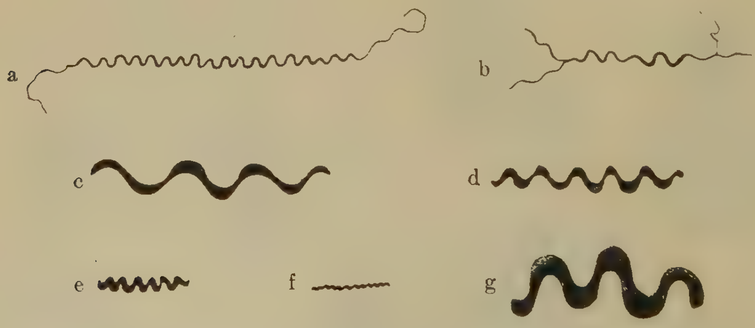


Fig. 62.

Schematic drawing of undulating membrane of Spirochaetes. *a* and *b Spirochaeta pallida; c, S. refringens; d,* a small Spirochaete of the same species; *e,* Spirochaete found in an ulcerated carcinoma; *f, Spirochaete dentium; g, Spirochaeta plicatilis* merely showing the extremity of a rather long individual. (After Schaudinn).

Cause of **syphillis.**

Acquired syphillis is due to a mucous membrane coming in contact with the spirochete.

Congenital syphillis is transmitted through the mother to the child.

The **treponema** is a spiral, curved organism from 5 to 15 microns in length, showing active movements in fresh specimens.

Syphillis is one of the most serious and far-reaching of all diseases, in fact so far-reaching that one of the world's greatest diagnosticians has said that if one could know every ramification of this disease he would know nearly all there was to medicine. Doubtful if curable.

Though all symptoms are gone, the disease may appear again.

In fact, in prisons, where there was little likelihood of a second infection, symptoms have appeared ten years after a supposed cure.

THE PROTOZOA, SUMMARY OF IMPORTANT FACTS

(Table Modified from R. Hertwig and R. W. Hegner.)

1. The **Protozoa** are **unicellular organisms without true organs or true tissues.**

2. All **vital processes** are accomplished **by** the **protoplasm** (sarcode), **digestion directly** by its substance, **locomotion** and the **taking of food by** means of **protoplasmic processes** (pseudopodia), **or** by **appendages** (cilia and flagella).

3. **Excretion** takes place **by** special accumulation of fluid, the **contractile vacuoles.**

4. **Reproduction** is **by budding** or by **fission. Conjugation** has been witnessed in many, and possibly occurs in all. True conjugation is a process of **fertilization** (caryogamy), in contrast to **fusion of plasma** (plasmogamy).

5. Protozoa are **aquatic,** a few living in moist earth; they can only exist in dry air in the **encysted** condition, surrounded by a **capsule which prevents desiccation.**

6. Since **encysted Protozoa** are easily carried by the wind, the occurrence of these animals in water which originally contained none is easily explained.

7. The mode of locomotion serves largely as a basis for division of the Protozoa into the classes **Rhizopoda, Mastigophora, Infusoria** and **Sporozoa.**

8. The **Rhizopoda** are subdivided into the following orders: **Lobosa, Heliozoa, Radiolaria,** and **Foraminifera.**

9. The **Rhizopoda** have changeable protoplasmic processes, the pseudopodia.

10. Order 1. **Lobosa** ( ). Rhizopoda with fingerlike (lobose) pseudopodia. Most of the Lobosa occur in fresh water, a few in moist earth, and some are parasites.

Examples: **Amoeba, Arcella** and **Difflugia.** (Fig. 63 .)

Arcella ( ) is common in the ooze on the bottoms of fresh-water ponds and ditches. It has a dome-shaped brownish shell of chitin which it secretes. The lobose pseudopodia protrude from a circular opening in the center of the flattened surface.

Difflugia ( ) is another common member of the order Lobosa, and is also found in the ooze of ponds. Its shell consists of minute particles of sand and other foreign objects held together by chitin.

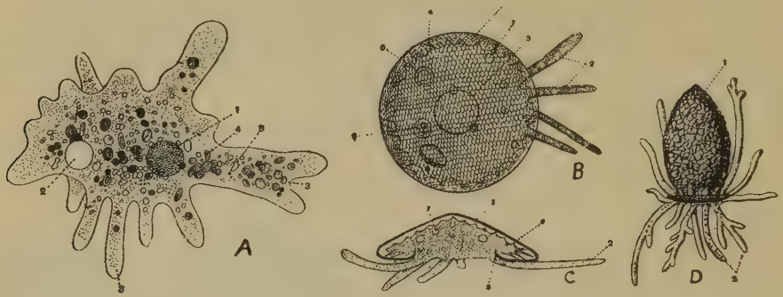


Fig. 63.

A. *Amoeba proteus.* (After Gruber).
B. and C. *Arcella discoides.* (After Leidy).
D. *Difflugia urceolata.* (After Leidy).

11. Order 2. **Heliozoa** ( ) Rhizopoda with thin, radially arranged pseudopodia, which are usually supported by axial threads.

Examples: **Actinophrys.** (Fig. 64.)

Actinophrys ( ), the sun animalcule, lives among the aquatic plants in fresh water ponds and ditches. The body appears vesicular, being crowded with vacuoles. The small organisms which serve as food strike the pseudopodia, pass down to the body, and are engulfed; larger organisms are drawn in by several neighboring pseudopodia acting together.

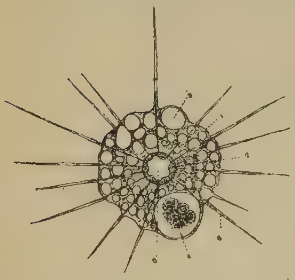


Fig. 64.

Actinophrys sol × about 800. (From Bronn.)

12. Order 3. **Radiolaria** ( ) Marine Rhizopoda with raylike pseudopodia, a central perforated capsule of chitin, and usually a larger enclosing skeleton of silica.

Examples: **Actinomma, Thalassicola.** (Fig. 65.)

The shells of the radiolarians, upon sinking to the sea bottom, form radiolarian ooze; this becomes hardened, producing rock strata as much as 1,000 feet thick. These rocks may take the form of quartzites, flint, or chert concretions.

13. Order 4. **Foraminifera** ( ) Rhizopoda, mostly marine, with fine, branching pseudopodia which fuse forming a protoplasmic network.

Examples: **Allogromia, Globigerina.** (Fig. 66.)

Allogromia ( ) lives in fresh water and has a

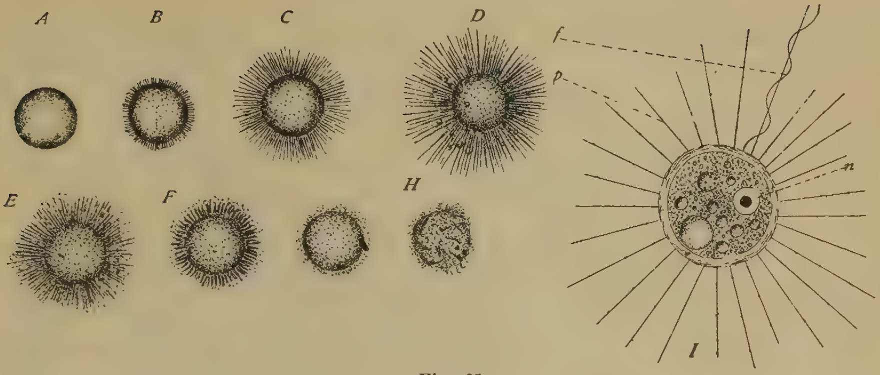


Fig. 65.

A. to H. Isolated Nucleus of *Thalassicola nucleata Hux.* (After Verworn.)
A. to D. Regenerative changes.
E. to H. Degenerative changes.
I. *Actinomonas Pusilla* (Kent) *n*, nucleus; *f*, flagellum; *p*, pseudopodia.

chitinous shell. The shells of many Foraminifera consist of numerous chambers connected by openings (foramina), and are composed of calcium carbonate. When these shells sink to the sea-bottom, they become Globigerina ooze, which solidifies, forming gray chalk.

14. The **Mastigophora** ( ) may easily be distinguished from other Protozoa by the presence of one or more flagella. Four orders are usually recognized: (1) **Flagellata,** (2) **Choanaflagellata,** (3) **Dinoflagellata,** (4) **Cystoflagellata.**

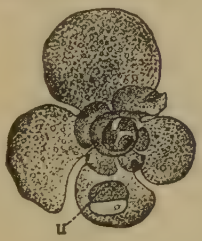


Fig. 66.

Protoplasm of *Globigerina*, after the shell has been dissolved. *n*, nucleus. (After Hertwig.)

15. Order 1. **Flagellata** ( ) Mastigophora with one or more flagella at the anterior end of the body.

Examples: **Euglena, Mastigamoeba, Chilomonos, Uroglena, Volvox.** (Fig. 67.)

Mastigameba ( ) is of special interest, since it appears to combine the distinguishing characteristics of both the Rhizopoda and Mastigophora, that is, it possesses pseudopodia

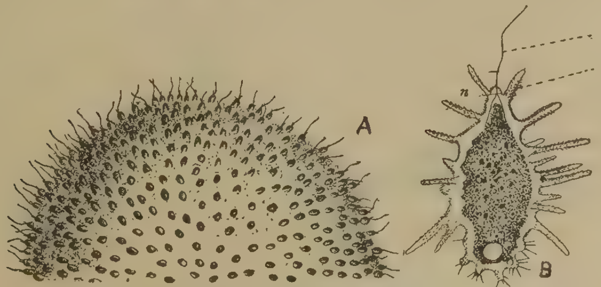


Fig. 67.

A. *Uroglena americana* Calkins, a sphaeroid colony.
B. *Mastigamoeba aspera*. (After Schultze).

and also a distinct flagellum. It is therefore able to creep about on a solid object or swim directly through the water.

Chilomonas ( ) is a very common Flagellate in laboratory cultures. **Uroglena** forms spheroidal colonies consisting of a great number of individuals held together by a gelatinous matrix. This form is often responsible for the **"oily odor"** of drinking water caused by the escape of small droplets of an oil-like substance from the cells.

Volvox ( ), (Fig. 49), is a colonial Flagellate found in fresh-water ponds. It may consist of as many as twelve thousand cells. Protoplasmic strands connect each cell with those that surround it; **physiological continuity** is thus established. All of the cells are not alike, since some of them, the **germ cells,** are able to produce new colonies, but others, called **somatic** or **body cells,** have no reproductive power.

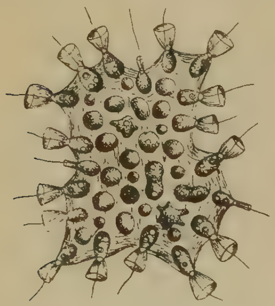


Fig. 68.
Proterospongia haeckeli S. K. (S. Kent).

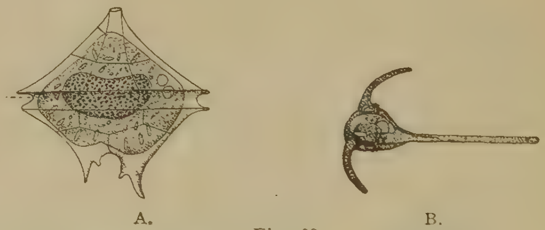


Fig. 69.
A. *Peredinium divergens, chr.*
B. *Ceratium tripos* (Calkins). (From Pratt's "Manual" by permission of A. C. McClurg & Co.)

Some of the germ cells, the **parthenogonidia** ( ), grow large, divide into many cells, drop into the center of the mother colony, and finally escape through a break in the wall. Other germ cells produce by division a great number of minute microgametes or

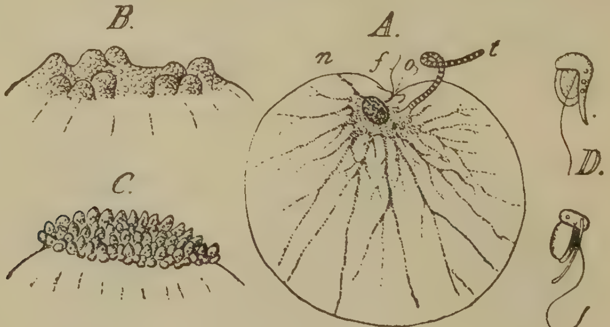
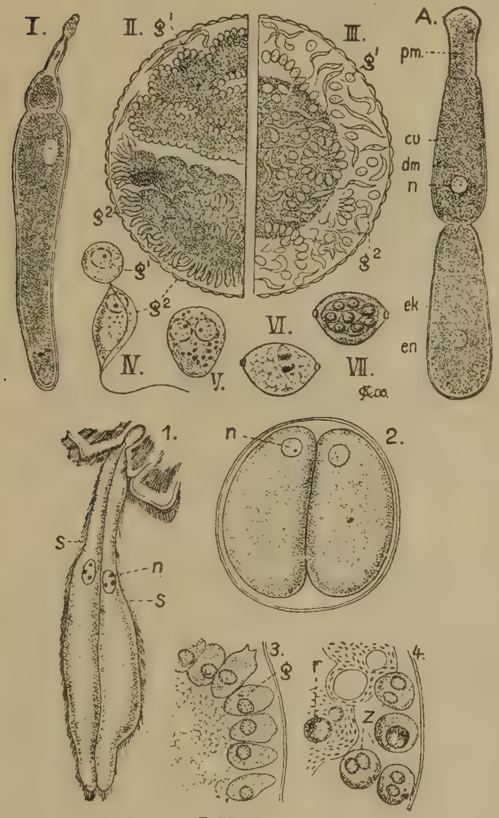


Fig. 70.

Noctiluca millaris. A, entire animal; *f*, flagellum; *n*, nucleus; *o*, cytostome and beside it the tooth and lip; *t*, tentacle; B, C, upper end with two stages in the formation of zoospores; D, zoospores. (After Hertwig.)

spermatozoa, and still others grow large, becoming macrogametes or **eggs**. The eggs are **fertilized** by the spermatozoa, and, after a resting stage, develop into new colonies.



I–VII.

Fig. 71.

Different Gregarina. *I-VII*, development of *Stylorhynchus; I*, S. *longicollis; II*, encysted S. *oblongatus* (two animals) beginning gamete formation; *III*, same later when the sexually differentiated gametes are copulating; *IV-VII*, formation and development of zygote of S. longicollis more enlarged; *IV*, copulation of gametes; *V*. *longicollis* more enlarged; *IV*, copulation of gametes; *V*, A, *Clepsidrina blattarum*. *1-4*, *Monocystis magna*. *1*, two individuals copulating while in the spermatheca of an earthworm, surrounded by spermatozoa; *2*, encysted; *3* and *4*, parts of cysts, formation and conjugation of the more enlarged gametes. *cu*, *cuticula*; *dm*, deutomerite; *ek*, ectosarc; *en*, entosarc; *g*, gametes; *g1*, zoospores; *g2*, oospore; *pm*, protomerite; *n*, nucleus; *r*, residual body; *s*, sperm of earthworm; *z*, zygote. (From Hertwig after various authors.)

16. Order 2. **Choanoflagellata** ( ) Mastigophora **with a** contractile protoplasmic collar from the bottom of which extends a single flagellum.

Examples: **Monosiga, Proterospongia.** (Fig. 68.)

17. Order 3. **Dinoflagellata** ( ) Mastigophora with two flagella, one at the anterior end, the other passing around the body, often in a groove.

Examples: **Peridinium, Ceratium.** (Fig. 69.)

18. Order 4. **Cystoflagellata** ( ) Mastigophora with two flagella, one resembling a tentacle, the other lying in the gullet.

Examples: **Noctiluca, Leptodiscus.** (Fig. 70.)

Enormous numbers of **Noctiluca** ( ) are often found floating near the surface of the sea, giving it the appearance, as Haeckel says, of "tomato soup." At night they are phosphorescent, emitting a bluish or greenish light.

19. The **Sporozoa** ( ) are Protozoa without motile organs. They are **parasitic in Metazoa.** Reproduction is mainly by spore formation. The following classification is simplified from Minchin's account in Lankester's **Treatise on Zoology**, Part 1:

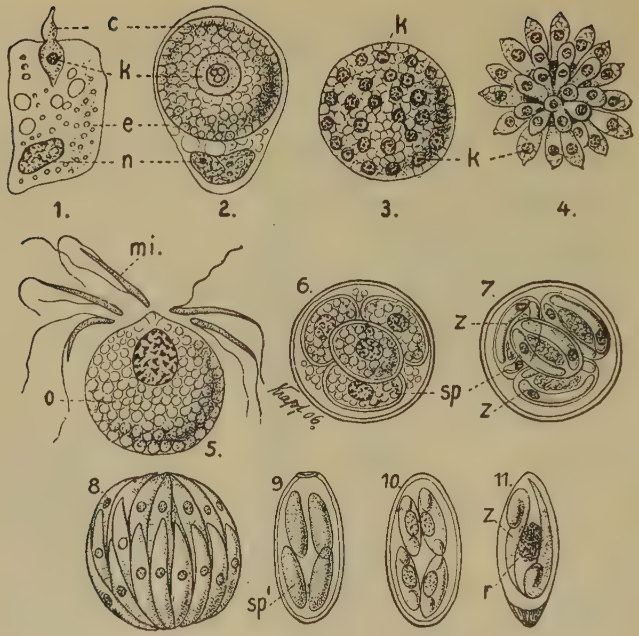


Fig. 72.

Development of *Coccidium schubergi* *1*, entrance of sporozoites in cell; *2*, its growth; *3*, nuclear multiplication; *4*, division into merozoites; *5*, macro-and microgametes; *6*, zygote divided into four sporozoites. *8-11*, *Emeria stiedae*. *8*, auto-infection; *9*, formation of sporoblasts; *10*, change of spores into sporozoites; *11*, spore with two sporozoites, much enlarged; *c*, *z*, sporozoite; *e*, epithelial cell; *k*, *n*, nucleus; *mi*, microgamete; *o*, macrogamete; *r*, residual body; *sp*, spore; *sp'*, sporoblasts. (1-7 after Schaudinn; 8-11 after Wasielewsky and Metzner).

20. Subclass 1. **Telosporidia** ( ) Sporozoa in which the life of the individual ends in spore formation.

21. Order 1. **Gregarinida** ( ) Telosporidia possessing a firm pellicle and complex ectosarc; intracellular during the early stages of the life cycle, later free in the body cavities of invertebrates.

Examples: **Monocystis, Porospora, Gregarina.** (Fig. 71.)

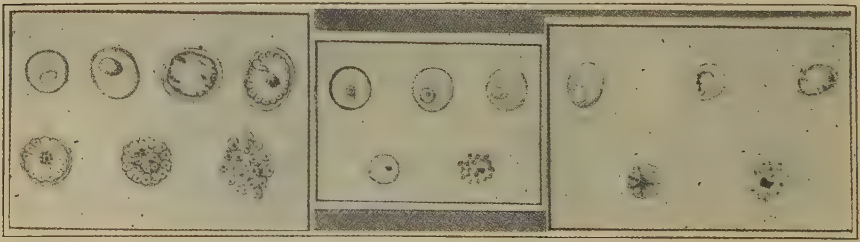


Fig. 73. *Plasmodium malariae.*

A. Parasites of tertian malaria.
B. Parasites of estivo-autumnal malaria.
C. Parasites of quartan malaria. (After Thayer and Hewetson).
(From supplement No. 18 to the Public Health Service, Jan. 20, 1915.)

Monocysts (   ) may be found in the seminal vesicles of almost every earth-worm; **Gregarina** is a common parasite of the cockroach; and **Porospora gigantea,** which reaches a length of two-thirds of an inch, inhabits the alimentary canal of the lobster.

22. Order 2. **Coccidiidea** (   ) Telosporidia simple in structure; trophozoite is a minute intracellular parasite.

Example: **Coccidium.** (Fig. 72.)

Members of this order are sometimes found in the liver and intestine of man and other vertebrates, and in Arthropoda and Mollusca.

23. Order 3. **Haemosporidia** (   ) Telosporidia parasitic in the blood of vertebrates.

Example: **Plasmodium.** (Fig. 73.)

24. Subclass 2. **Neosporidia** (   ) Sporozoa which give rise to spores at intervals during active life.

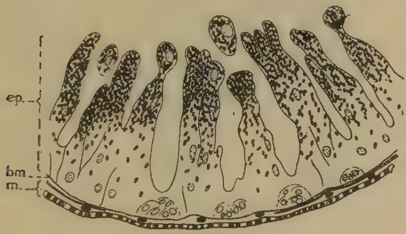


Fig. 74.

Nosema. Longitudinal section of stomach of honeybee showing infection with *Nosema apis*: *ep*, Epithelial portion, containing spores of the parasite stained black. (The younger parasites, not differentiated so easily by staining, are not shown; they are found toward the base of the cells reaching the basement membrane (*bm*), but do not extend beyond it. Younger spores sometimes show an unstained area at one end and occasionally at both ends. *m*, muscular portion of stomach wall showing an outer and an inner longitudinal muscular layer and a middle circular one. (After G. F. White, U. S. Dept. of Agriculture Bulletin No. 780.)

25. Order 1. **Myxosporidia** (   ) Neosporidia with ameboid intercellular trophozoite.

Example: **Nosema.** (Fig. 74.)

The Myxosporidia are parasitic especially in Arthropoda and fish, frequently causing serious epidemics in aquaria. **Nosema bombycis** produces the silkworm disease, **pebrine.**

26. Order 2. **Sarcosporidia** (   ) Neosporidia usually parasitic in the muscles of vertebrates.

Example: **Sarcocystis.** (Fig. 75.)

The most common Sarcosporidia are **Sarcocystis miescheriana** in the muscle of the pig, **S. muris** in that of the mouse, **S. lindemanni,** rarely occurring in the muscles of human beings.

27. **The Infusoria** (   ) are Protozoa with cilia which serve as locomotor organs and for procuring food. **Paramecium** is a typical member of the class. There are two subclasses, (1) **Ciliata,** and (2) **Suctoria.**

28. Subclass 1. **Ciliata** (   ) Infusoria with cilia in the adult stage, a mouth, and usually undulating membranes or cirri. Many ciliates are confined to fresh water, others occur either in fresh or salt water, and still others are parasitic in Metozoa.

29. There are four orders: (1) **Holotricha,** (2) **Heterotricha,** (3) **Hypotricha,** (4) **Peritricha.**

30. Order 1. **Holotricha** (   ) Ciliata with cilia all over the body and of approximately equal length and thickness.

Examples: **Paramoecium, Coleps, Loxophyllum, Colpoda, Opalina.** (Fig. 76.)

The Holotricha are probably the most primitive Infusoria. **Paramoecium caudatum** is the best known species. Members of the following genera are frequently found in fresh-water cultures: **Coleps, Loxophyllum,** and **Colpoda. Opalina ranarum** is a large multi-nucleate species living in the intestine of the frog. It has no mouth, but absorbs digested foods through the surface.

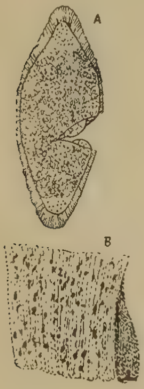


Fig. 75. *Sarcocystis miescheriana.* (Doflein.)
A, a cyst; B, Pork containing cysts. (From Pratt's "Manual" by permission of A. C. McClurg & Co.)

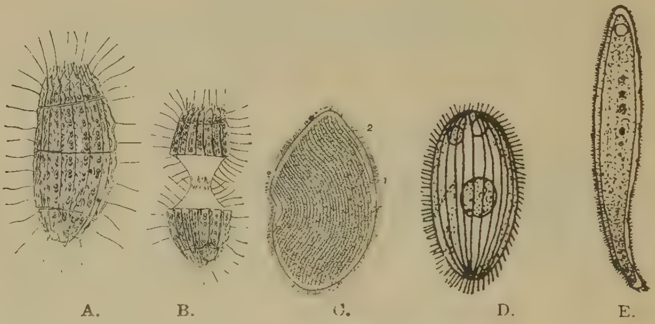


Fig. 76.
A. *Coleps hirtus Ehr.* (After Maupas).
B. Division phase of A.
C. *Opalina ranarum,* (After Bronn).
D. *Colpidium colpoda.* (Calkins).
E. *Loxophyllum rostratum* (Conn.)

31. Order 2. **Heterotricha** ( ) Ciliata whose cilia cover the entire body, but are **larger and stronger about the mouth** opening than elsewhere. This adoral ciliated spiral consists of rows of cilia fused into membranelles and leads into the mouth.

Examples: **Spirostomum, Bursaria,** and **Stentor.** (Fig. 77.)

Stentor ( ) may be either fixed or free swimming. It is trumpet-shaped when attached and pear-shaped when swimming. The cuticle is striated and just beneath it are muscle fibers (myonemes). The nucleus is ellipsoidal, or like a row of beads.

32. Order 3. **Hypotricha** ( ) Ciliata with a **flattened body** and dorsal and ventral surfaces. The **dorsal surface is free from cilia,** but **spines may be present.** The ventral surface is provided with longitudinal rows of cilia and also spines and hooked cirri, which are used as locomotor organs in creeping about. The cilia around the oral groove aid in swimming as well as in food taking. There is a macronucleus, often divided, and two or four micronuclei.

Examples: **Oxytricha, Stylonychia.** (Fig. 78.)

33. Order 4. **Peritricha** ( ) Ciliata with an

adoral ciliated spiral, the rest of the body is without cilia, except in a few species where a circlet of cilia occurs near the aboral end.

Examples: **Vorticella, Carchesium, Zoothamnium.** (Fig. 79.)

The common members of this order are bell-shaped and attached by a contractile stalk. Certain species are solitary (**Vorticella**), others form tree-like colonies (**Carchesium**), and still others are colonial but with an enveloping mass of jelly (**Zoothamnium**). The stalk contains a winding fiber composed of myoneme fibrils; this fiber, on contracting, draws the stalk into a shape like a coil spring.

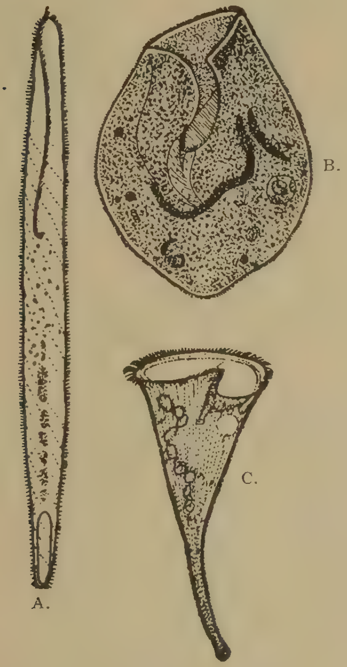


Fig. 77.
A. *Spirostomum teres* (Conn).
B. *Bursaria truncatella* (Conn).
C. *Condylostoma patens.* (Calkins.)
(From Pratt's "Manual" by permission of A. C. McClurg & Co.)

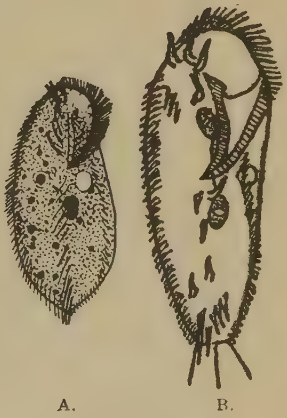


Fig. 78.
A. *Oxytricha bifaria* (Conn).
B. *Stylonychia mytilus* (Doflein).
(From Pratt's "Manual" by permission of A. C. McClurg & Co.)

34. Subclass 2. **Suctoria** ( ) Infusoria **without cilia in the adult stage.** No locomotor organs are present and the animals are attached either directly or by a stalk. No oral groove nor mouth occurs, but a number of tube-like tentacles extend out through the cuticle.

Examples: **Podophyra, Sphaerophyra.** (Fig. 80.)

Ciliates are captured by their tentacles and the substance of the

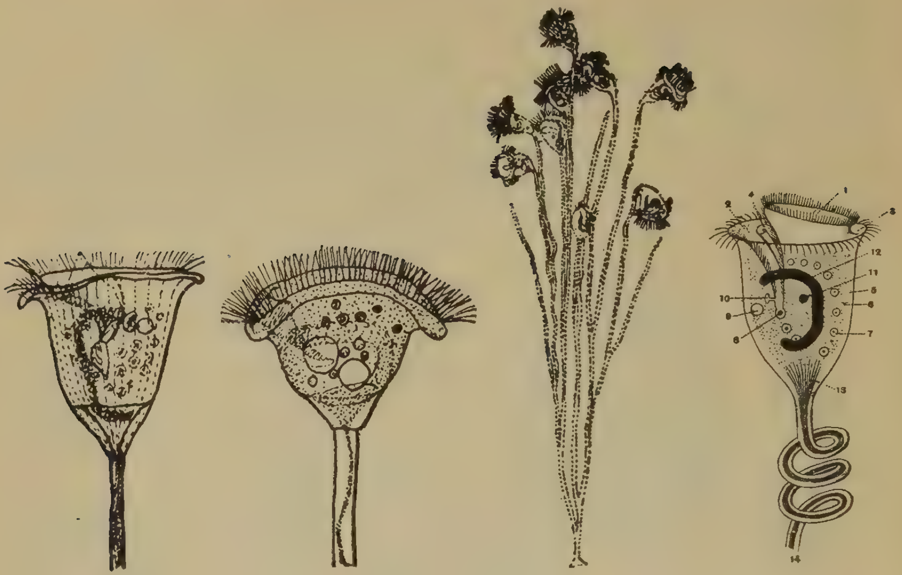


Fig. 79.
A. *Vorticella nebulifera* (Bronn).
B. *Vorticella patellina* (Calkins).
C. *Carchesium polypinum* (Doflein).
D. Diagram of *Vorticella*. The cilia at the side of the mouth have been omitted. (From Pratt's "Manual" by permission of A. C. McClurg & Co.)

captured prey is sucked into the body. Both fresh-water and marine species are known. **Podophyra** is a well-known fresh-water form. **Sphaerophyra** is parasitic in other Infusoria.

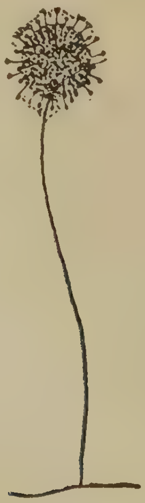


Fig. 80.

Podophyra gracilis. (Calkins). (From Pratt's "Manual" by permission of A. C. McClurg & Co.)

CHAPTER X.

INTERPRETATIONS OF THE FACTS THUS FAR PRESENTED.

The far-reaching importance of biology may be shown by obtaining an understanding of this fact: that, when anyone wishes to discuss **inheritance, environment, training,** or any of the many philosophies, or **theories of life,** some **physical** (biological) **background** must be found or the discussion is not likely to impress many. A conception of such background may be gained by reviewing the following facts just studied:

The little cigar-shaped animal known as **Paramoecium** is found in fresh water. It moves about rapidly by means of tiny hair-like projections which cover its entire body. There are in reality **only two movements** it can perform. It **goes forward** and **background** constantly, turning its body over and over so that its path is spiral-shaped. A groove extends half way down the length of the body into which particles of food are swept as the animal moves forward. The mouth being located at the lower end of this groove, the food is thus conveniently forced into it and swallowed.

The entire animal is composed of a thick substance looking something like the white of an egg, but that this thickened material is not all alike is attested by the fact that a drop of alcohol placed upon it causes the outer portion of the animal's body to swell up like a blister while the same alcohol apparently has no effect upon the internal structure. Then, too, if **Paramoecia** are placed in a staining fluid, **two spots** take the color much better and much deeper than do other parts of the body, showing that the two spots which thus take the stain are of different chemical composition from the other parts. Were all the substance alike it would all stain alike. These stainable spots we call **nuclei.**

Everyone has observed that all living things who fulfill their normal span of life are subject to the same natural laws, such as being born, growing to maturity, and dying. The nearest thing to an exception to this general rule is found in the little single-celled animal of which we are speaking. This little fellow is **not born.** When it is time for its parent to pass from this earthly region as an individual, it merely divides into two separate and distinct animals (Fig. 81).

There are now two Paramoecia where there was only one before. This is significant. The two new animals **(each consisting of one-half of its parent)** again divide into two separate animals, and so continue dividing indefinitely. The greatest number of divisions observed so far is six thousand. This means that **Paramoecia** do not die, though they can be killed, for example, by boiling, by acids of various descriptions, and in other ways. It means further, that every **Paramoecium** now in existence is **actually a part of all its ancestors**, or to be more accurate, **it is its ancestors**, for these ancestors have never ceased to be. This must necessarily be true, because each ancestor merely divided into two offspring, the offspring thus being in reality the parent itself. This is vastly different from a parent giving birth to an offspring and then dying.

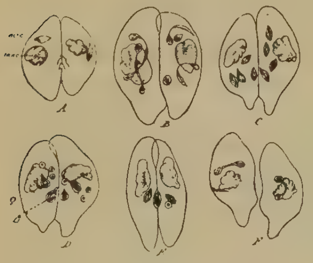


Fig. 81.

Stages in the conjugation of *Paramoecium caudatum.* *A,* Stage A, the micronucleus in each gamete preparing for division. *B,* Stage B, the daughter nuclei in each gamete dividing. *C,* Four micronuclei in each gamete. *D,* three of the four micronuclei are disintegrating; the surviving nucleus in each gamete has divided to form ♂. the male, and ♀. the female pronucleus. *E,* The male pronuclei crossing over. F, Conjugation effected; separation of the gametes and division of the combination nucleus. (After Maupas.)

It is an established and incontrovertible biological fact that **no living cell can come from anything but a previous living cell. No organism or living thing can possibly come into existence except from some previously existing living parent form.**

Now, if sufficient food is given **Paramoecia** they will keep on dividing several hundred times, but then, if they are with others of their kind an interesting event takes place. Two of the animals will swim around and around, finally attaching themselves to each other lengthwise while the wall of each animal that comes in contact with its mate seems to disappear, the two animals becoming **almost**, but not quite, one individual.

The smaller colorable spot in each animal now begins to divide into two parts as shown in the drawings. These parts again divide, making four pieces to each nucleus. Three of these pieces disappear (probably they are dissolved in the body substance), but the one remaining piece then again divides into two pieces, one of which remains more or less stationary while the other (often partially connected with the first) moves toward the midline of the two connected animals to meet with a similar movable piece of stainable matter from the attached individual. The two pieces of movable-stainable-matter **become one for a short period,** seemingly exchanging some of their substance, then they again separate and go back to form a nucleus like the one from which they sprang.

The animals themselves now separate, and each begins its division into two new animals, which again divide, such division continuing as already mentioned, several hundred times, until this same **conjugation** or joining process is brought about again. The larger stainable-spot is dissolved at the time of conjugation and is thought to have some nutrient function.

It is the **nuclear material** which seems to be the **important physical matter** in the formation of any living thing—plant or animal—and in turn it is only the colorable matter inside the nucleus known as **chro-**

matin, which breaks up and divides, and is carried on from parent to offspring. These little broken pieces of chromatin are called **chromosomes.** The chromosomes have come to be considered the most important factors throwing light on the many problems of inheritance—that is, on all problems that pertain to what we actually obtain from our parents, whether these be physical, emotional, or intellectual.

It is therefore of decided importance that we obtain a clear conception of chromosomes, because in the final analysis every detail of what we are and can be, that has any relation whatever to our physical, emotional, and mental makeup must come from our parents through the chromosomes in the egg-cell of the mother and the sperm-cell of the father. In other words, the chromosomes that were ours at the moment of mixture of sperm and egg, possessed the sum total of all the actual physical, mental, and emotional endowment with which we were possessed when ushered into the world (except food and environment needed for growth, as well as a place to grow).

In the case of **Paramoecia the animal does not inherit anything from its parent—it is half of its parent.** Each **Paramoecium** is thus equivalent to an egg-cell or a sperm-cell, though there is no sex present in **Paramoecia. The offspring is not a chip from the old block—it is half the block.**

An interesting application follows.

In every living thing where observation of chromosome material has been possible, life begins from an egg-cell of some kind, and in the higher forms this egg-cell receives one-half the chromosomes from the sperm after the egg-cell itself has cast out one-half of its own chromosomes. There is thus a constant trend toward forming **an average** individual of the species to which each such individual belongs, for, each new living thing that comes into being is made up of one-half the chromosomes which the maternal egg-cell possessed, and one-half of those which the paternal sperm-cell contained.

If this were not so, then in those cases in the animal world where we have virgin-birth, there would be an ever lessening quantity of the chromosome material in each next generation, so that each offspring would become more and more unlike its parent, until in time, when no fertilization takes place to restore the proper quantity of chromosome material by a paternal sperm-cell being added to the maternal egg-cell, the offspring would not be recognized as a member of the species to which its ancestors belonged.

Every female at the time of her birth **has every egg in her body that she will ever have.** This is as true of a bird as of a human being. In the human there are about 35,000 eggs in each of the two ovaries, though only about 100 to 200 of these actually ripen and pass out of the body during the sexual life of the individual. This means that the mother has little or no influence **on the formation** of the egg, **it being already complete by the time she herself is born.**

The eggs lie dormant and do not begin to ripen until sexual life begins (averaging from twelve to fifteen years in the human being). But, when an egg does ripen, an interesting process takes place. It is expelled from the ovary immediately and, just as **Paramoecia** split into two parts, so does the egg. But the **egg does not divide equally.** A little piece called the **polar-body** separates from the main part of the egg. This polar-body may divide again, but even so, it deteriorates and can be seen no more in a short time. The stainable nuclear material breaks up into a number of chromosomes just as does the chromatin of the **Paramoecium,** and one-half of these chromosomes remain in the larger portion, the other half passing into the polar-body to deteriorate with that part.

The **head** of the male cell (spermatozoan) **is practically all nuclear material** and goes through approximately the same process as the egg does except that the sperm divide **equally as to size,** thus forming **two definite, living sperm-cells where there was only one before**—again, this is just like **Paramoecia.** And here, too, the chromosomes divide equally, so that each sperm has only one-half the full number of chromosomes it had before it divided.

As every plant and animal that lives comes into existence in practically the same way, that is, through a single cell of the father and a single cell of the mother uniting, we see that this is nature's way of bringing together the **normal number of chromosomes** needed **to make a complete individual.** This again means that each individual thus comes into possession of one-half the traits or capacities of each **parent-cell** (not necessarily one-half of the traits or capacities of the parent) from which he sprang. Were this not true, each and every one of us would be quite unlike our parents, because each would be less than either parent, instead of each taking one-half from each parent and thus becoming a complete human being like both. As our parents can give us **only** the **single egg-cell** and the **single sperm-cell,** everything else being merely food and environment, **it follows that everything we can possibly inherit as to our physical and mental makeup must be in the chromosomes that these eggs and sperm contain**; for, **it is only the chromosome part that intermingles, divides, and causes new cells to form.**

For anyone wishing to study life, therefore, the study of **chromosomes** looms up as **the most important factor.**

The laboratory study of the fertilized cell of which we are speaking has shown that each such fertilized cell divides into two cells, these two into four, each of these four into two, making eight, these eight into sixteen, and so on indefinitely until the entire body has finished its growth.

The first group or sheet of cells becomes a **hollow sphere** called a

blastula. Some animals stop growing at this stage. Others continue growing, which means that this single-layered sphere **indents** and this indentation extends into the sphere until **two layers** of cells are formed. This is called the **gastrula** stage. Animals having two layers stop growth when this stage is reached, while all higher forms produce a **third layer** of cells between these two.

Every living thing passes through one or more of these developmental processes. It was this fact which led so many of the early biologists to suppose that each developmental stage meant that each one of the higher forms of animals must have sprung from those which stopped in the one and two-layer stage just beneath the higher form. What it does mean, however, is that all living forms pass through **a similar** state of growth.*

Very early in this development of an egg, **after** it begins to grow (fertilization apparently furnishes this growth impulse), **certain cells divide much more rapidly** than do others. The rapid-growing cells consequently, soon **surround the less-rapidly** growing ones, thus forming a sort of protecting case or capsule for them. Now, some of the very first cells that are thus protected and grow into the very innermost portions of the growing **embryo**, are the egg-cells and the sperm-mother cells. This occurs long before one can even distinguish what kind of an animal the embryo is to become.

It was Professor August Weismann of the University of Freiburg in Baden, who in 1892 gave the world his book, "The Germ-plasm, a Theory of Heredity," which has made us interpret the various facts so far mentioned in a different way from what had been done before. Up to that time men said that the reason a boy so closely resembled his father was because he was "a chip **from** the old block," Professor Weismann has shown us that this is incorrect, and **that both father and son are pieces from the same block.** That is, the **sex-cells** in **both mother** and **father** being a part of the earliest differentiation in the growing embryo as already shown, are really placed in position in the child **before he is born,** so that a parent simply considered as a parent has absolutely nothing whatever to do with the matter, such parent's body acting only as a case or capsule which carries the germ-cell to the next generation.

This is made clearer when it is remembered that every egg in every female is already present at the time of such individual's birth. All that happens during her life is a **ripening,** or **maturing,** of such egg, and fertilization by the male sperm. The sperm-mother-cells that are to divide and form sperm, are **already present** in the male child when he is born, though they begin to divide only after puberty.

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*It does not follow that because a man builds a school, a barn, and a church, that the church must therefore have first been a school and a barn, even though such builder used exactly the same tools and similar material in the building of each structure; in fact, it would not follow, even though he build the foundation and the first story of each structure exactly alike in each case.

The sex-cells are therefore present at birth in each person, and no one can either change or add anything to them, unless, again it be merely the food and drink he takes that may or may not nourish such sex-cell properly.

This means, then, that just as with **Paramoecia**, each and every one of us cannot obtain from our parents one more particle of physical, emotional, or mental ability than our parents may have had, because we get only what was present in the egg-cell of our mothers and the sperm-cell of our fathers.

It means further, that when we go back even twenty-five generations, considering our two parents, four grand-parents, eight great-grand-parents, etc., we are related in actual blood-relationship to more people than there are in the world at the present time. It means that just as **Paramoecia** are really their grand-parents and all their ancestors in one, so **we are also actually and truly our own ancestors in so far as our sex-cells are concerned.**

An actual living particle of every one of our forefathers is really present in each one of us. It means that the entire animal world, including the human family, by constant intermingling of chromosomes, is always tending toward **an average**, so that **no matter how many centuries elapse there is no real individual physical or biological progress possible. Always will the next succeeding generation, or at least the next after that, have some sex-cells in their bodies that will again produce an average being.**

This **sex-bridge** which connects every human being with every other human being in this way, is sometimes referred to as the **Weismannian bridge.** It is this bridge which is both the hope of an oppressed people and the despair to those who would change human nature from what it is. We can build only upon instincts; upon human desires and upon wishes which are ours at birth, though we may **develop** such instincts and desires, **but no actual change in human nature can possibly ever come into existence.** Human nature is the same now as it has ever been and always must be, until some method be obtained by which we can tell in advance by looking at a chromosome, what good and bad characteristics such chromosome contains, and then be able to destroy the bad therein. This means that we are aeons and aeons removed from any solution to our **eugenic problem** on a **truly scientific basis.** Even then, were we able to accomplish this practically impossible task, we should still have to evolve some plan by which we could see the egg and the sperm before they unite, a task again practically impossible until **new** human beings can be grown in the laboratory.

Professor Weismann also demonstrated to the scientific world that the germ-plasm **early separates** from that part which is to become the **outer portion** of the body and which is called the **somatoplasm.**

The **Abbott Mendel** has proved that no matter how much interbreeding there may be among plants or animals, there are only two types of offspring produced, i. e., **pure stock** and **half breeds.** The **eggs** and **sperm** in the germ-plasm **always remain pure.** That is, if a **white** and **black** animal **mate, a portion of the eggs** in the ovary of any female offspring from such union will be **carriers** of **pure black** and **a portion** will be **carriers** of **pure white characteristics.** The **sperm** of the male, **likewise,** are **carriers** of **one or the other colors,** but are **not themselves half-breed.** It will be noticed, therefore, that from this **Mendelian theory** additional evidence is brought forth to substantiate the Weismannian theory of germ-plasm, which holds that the germ-plasm is separate and distinct from the rest of the body.

The **color of the skin** of any offspring **of black and white** animals may be of **any shade,** from pure black, to almost, or entirely white. **But the sperm and the egg have not intermingled in so far as color is concerned.** The **color** shows up on the **outer part** of the body, or in what we call the **somatoplasm.** The **germ-plasm always remains pure,** so that in the next succeeding generation, if any of these half-breeds in turn mate with each other we have the four possibilities of a **white sperm** meeting with a **black egg** and again **producing a half breed,** or a **black sperm** mixing with a **black egg** which produces a **pure black,** while a **black sperm** with a **white egg** produces a **half breed,** and a **white sperm** with a **white egg** produces a pure white.

From observation, however, it is found that the **half breeds will look like one or the other of their parents in so far as color** of skin, eyes, and hair is concerned. **Whatever color** the offspring shows is known as the **dominant** color.* We cannot tell, however, until we observe the first brood of half breeds which is the dominant color.

We do not know why one characteristic is thus dominant, but the important thing to remember is that this entire possibility of any of the four possible matings mentioned above, taking place in any mixed offspring is all a **matter of chance.** Having observed thousands of instances of this kind among both plants and animals, scientific men now accept it as a fact that we **do** obtain **two pure bloods,** and **two half breeds** from matings of mixed ancestry. It will be noticed that this is **pure chance,** there being approximately **half as many carriers** of **either color** in **each sperm of the male** as there is **in each egg of the female.** Therefore, there is **just as much likelihood at any given time of a black**

**Recessive* is the word set in opposition to *dominant.* A recessive characteristic is *always present* in the germ-plasm of an animal or plant of *mixed ancestry,* but it *does not show* in the somato-plasm—in any part of the *body proper outside the germ-plasm.* The dominant characteristics *cover up* the recessive characteristics. For example, in half-breed offspring—a cross between white and black parents—if all these half-breeds are black, we *call black* the dominant characteristic *as to color,* though such half-breed has just as much *white* in him as he has black. The white which is *present but which is not seen* is called the recessive charasteristic.

It is very important, however, to remember that in so far as the germ-plasm—the sex cells themselves, that is, the eggs and sperm—is concerned, each egg and each sperm has roughly speaking, *one-half* black and *one-half* white characteristics; but the *dominant characteristic* is the only one which *shows,* and that only in that part of one's make-up *which is not germ-plasm.*

To clarify the matter; if half-breeds, which are the offspring of black and white parents are *all black,* we call *black* the dominant color.

sperm meeting a white egg as of a white one meeting a black, and vice versa. But it must not be forgotten **that not only the half breeds,** but **also the pure bloods of the dominant type** will all probably **look alike** as to color. This appearance of the **same color in the half-breeds** that appeared in the dominant pure-blood, is the thing which confused men for many years, and it was only after Abbott Mendel gave us his explanation that we have been able to understand why this is so.†

Mendelism has also added some interesting biological speculations to the earlier idea of naturalists.

If we define **species,** as meaning **all those particular plants and animals which can interbreed** and in turn give birth to fertile offspring, it can be seen immediately that we cannot have any **new species** at all, because, if the offspring of such plants or animals can give birth in turn to other offspring, they belong to the **same species** as do their parents, and if they differ in appearance from their parents they can only be called **variations** of the parent species. If they do not interbreed, or, if after interbreeding, they give birth to non-fertile offspring (such as the **mule,** which is the non-fertile offspring of a mare and a jack), then of course there can be no further offspring, and we can have no further species.

Mendelism has added a very important and interesting fact to such theorizing. For example, in the **dominant type of offspring,** there is always a **pure recessive sperm and egg,** so that it follows, that **at any time in the future, if by chance such pure egg and sperm meet, a totally different** type of plant or animal than its parent may be produced. But this may be merely **the coming forth** of a plant or animal **similar to some ancestral form,** which was the result of two recessive germ-cells meeting. Therefore, although these recessive germ-cells were always present in all ancestors, they were **covered up** in so far as external characteristics are concerned by the dominant characteristics. A new species, such as this which comes forth **suddenly,** is called a **"sport" in nature,** and the theory that all new forms come forth in this way is called the **mutation theory.** But, as these so-called new forms may be explained as being **recessives, again coming forth** after lying dormant for ages, there may be here no new species at all.

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†It is well to remember however, as Professor Darbishire has said, that, while on the Mendelian theory we know there are such things as *dominants* and *recessives* and that *unit characteristics of some types are transmitted from* parent to offspring, still, all the evidence we have so far is based upon color of eyes, straightness or curliness of hair, color blindness, and one or two other observations of this kind. It will be seen, therefore, that these are *not vital,* and may not be so important as we have thought them.

CHAPTER XI.

GENETICS

With a clear understanding of what has been said regarding the division of chromosomes in maturation described in a former chapter, and the discussion of interpretations in Chapter X, we are in a position to understand the terminology of heredity, genetics, and Mendelism, which is met with quite commonly in modern biological literature.

While genetics really means the "origin of things" it has come to be used as the name of that science which studies the ways and means by which **minor inheritable characters can be judged.** It must never be forgotten that to inherit anything from one's parents in the biological sense, means that the "something" which is inherited must already be present in the egg of the mother, or the sperm of the father, or in both these germ cells at the time the egg is fertilized. Every factor that may influence an organism, which is not already present in the gametes, is due to environmental conditions and cannot be said to be inherited.

At this point we must also remember the distinction made in a former chapter that germplasm and somatoplasm are entirely separate and distinct.

Mendelism, or rather Mendel's "law," merely means that each character that we may inherit must be considered as **a single unit**; that is, we must not think of a child as inheriting its father's hair because it has dark curly hair like its father, but we must think of darkness in color as one character of inheritance and curliness as another; for, a child may inherit the darkness in color from his mother and the curliness from his father.

Thinking in terms of **unit characters** will throw much light upon many of the interesting problems of life. We may thus account for one artist, for example, having a very decided sense of **form** and another of **color.**

It is now generally conceded by biologists that acquired characteristics are not transmitted to the offspring. We know, however, that brothers and sisters of the same family differ from each other in many respects. We know that no two leaves of grass are exactly alike; in other words, that all living things springing from the same parents vary somewhat from each other. It is the purpose of genetics **to find the mechanism by which such variation takes place** and then to be able to apply the knowledge thus gained toward bringing about the types of variations one wishes. Every variation represents a single unit character or a combination of these unit characters. One may use as an example the various species of cattle. Cows of a certain breed may produce a very rich milk but not a great quantity. Cows from another breed may produce great quantities of less rich milk, while those of still another breed living in the tropics may be more or less immune to heat and tropical disease. If one wishes to bring cattle into a rather hot clime, it will, therefore, be to one's advantage to obtain that breed which will produce the greatest quantity of good rich milk and likewise be able to withstand the great environmental change necessitated by removal from a temperate or cold clime to one of great heat.

We have already seen that the inheritable characters are contained within the chromosomes. The definite factors, whatever they may be, which carry the unit characters within the chromosomes are called **genes.**

From our knowledge, at the present moment, of the way the chromosomes divide in cell division, and the way they throw off one-half of their number during maturation just before fertilization so that fertilization can again restore the regular number, we are led to believe that no unit character can be inherited unless a gene from the father and a gene from the mother unite in the chromosomes.

We may say, for example, that all the unit characters which any individual can possibly inherit are contained within the chromosomes of the germplasm of its parents; that each chromosome may contain thousands of genes which may occur in any combination, the individual himself actually inheriting only those unit characters which happen to be the result of the particular gene of paternal and maternal chromosomes which met at the time of fertilization.

To make this clear let us assume that a white and black guinea pig are mated. The whiteness and blackness that we see, lie, of course, in the somatoplasm; but, in order that either color be inherited, there must be genes in the chromosomes of the germplasm which determine the somatic character of whiteness and blackness. We know that if a black guinea pig is mated with another black guinea pig, both of which are in turn the offspring of an entire race of black animals, that only black guinea pigs will be produced. However, if a black and white animal mate, the offspring are really **half-breeds,** in regard to their germ-cells, though their somatoplasm may show some variation in color. We, therefore, assume, from the experimental evidence obtained through breeding experiments of many kinds, that in order to produce a black animal, both the paternal and maternal genes, which carry the determination of color, must have carried blackness. In the production of a half-breed, one of the genes determining color must be white and the other black. (Fig. 82.)

In other words, two genes always meet to produce any character sufficiently powerful to be carried on, in turn, through succeeding generations, and the character which is thus carried on and which shows itself in the somatoplasm is called **dominant.** Blackness would thus be dominant when a white and black animal mate and produce half-breeds which are all black in color. However, as has already been stated, the color is only in the somatoplasm. It is important to remember that the germplasm remains **pure**; that is, some of the eggs in the mother and some of the sperm in the father will be of the black variety and others will be of the white variety. To put this in other words, **there will be no half-breed eggs or sperm.**

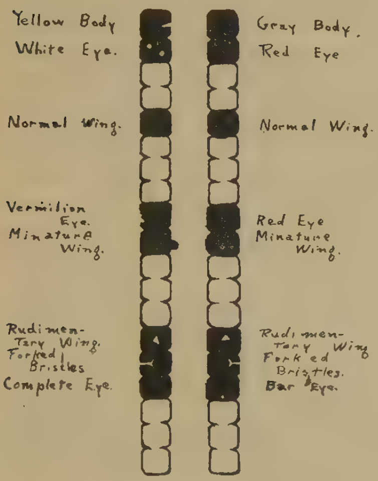

Fig. 82.

Diagram of two chromosomes, each square representing a gene.

An insect, for example, with these two chromosomes would possess a normal wing, a minature wing, a rudimentary wing, and forked bristles. All these characters could be transmitted to the offspring. The insects' body and eyes, however, would be heterozygous.

Whatever unit character shows up in the somatoplasm in animals of different breeds is said to be **dominant**, while that unit character which **is present** in the germplasm **but is not seen** in the somatoplasm is said to be **recessive.**

In our example of the mating of a white and black guinea pig the offspring, though black, have whiteness in their germplasm even if it does not show externally in the somatoplasm. Blackness in this case is therefore dominant; whiteness, recessive.

In their accounts of breeding experiments, geneticists use a formula to represent dominant and recessive genes. The capital letter represents the dominant gene and the small letter the recessive. In the example we have been discussing, the capital letter—B—would represent the gene which carries blackness, the dominant color; and the small letter—w—will represent the gene carrying the recessive white. The formula in our example of a halfbreed black and white, therefore, is—Bw—.

In those cases where pure blooded blacks would meet with pure blooded blacks the formula would be BB, while in the breeding of two pure whites the formula would be WW. It will therefore be noted that we may have the various formulas BB, Bw, WW, Wb, provided, of course, that a recessive black could be found.

Wherever two genes are alike, so that either has BB, or WW, the resultant zygote is called a **homozygote**, while the organism resulting from a homozygote is said to be **homozygous.** If the two genes of the mating pair are different, such as Bw or Wb, the zygote is called **heterozygote**, the resultant animal being called **heterozygous.** It is, of course, quite common for the same animal to be homozygous for some characters and heterozygous for others.

The parents are often represented by the capital letter P. The first generation (which means the offspring from these parents) are represented by the formula, F_1. The offspring of F_1 in turn are known as F_2, and so on, the F representing a final generation.

In many cases the various characteristics that the genes determine may be independent of each other, but, just as certain chemical elements have an affinity for each other, so there are various types of characters that often link themselves in the same way. This is known as **linkage.** Color of hair and the direction in which the hair grows, such as curliness, straightness, or whorls, are often linked. Then there are also certain types of **sex linkage** by which we mean that there are certain characters such as plumage in fowls and eye-color in flies which are almost always concomitant with the sex of the individual.

Much has been written on sex-determination in the past, though it is only recently that any progress has actually been made in this field. It has been found that sperm cells possess an extra or **accessory chromosome** (called an **X-chromosome** by American writers and a **heterotropic chromosome** by Europeans). (Fig. 30, A.) When such a sperm cell fertilizes an egg, a male is produced, while, when an egg containing a regular even number of chromosomes is fertilized by a sperm with an even number of chromosomes, a female is produced.

Interpreting these findings of the cytologists, biologists now believe that there is such an extra chromosome in both egg and sperm but that in the egg, this **X-chromosome** divides as do the others, although this division is delayed until some time after the other chromosomes have divided in the maturation divisions. This means that the **X-chromosome** of the sperm is really a **double chromosome** which fails to separate during spermatogenesis and consequently goes over to one of the two sperm-cells entire.

Then, in some organisms this **X-chromosome** has actually been seen to be made up of a larger and a smaller portion, while in the female of the same species both parts of the chromosome are of equal size. When the accessory chromosome is thus divided into two parts of different sizes, the smaller is called the **Y-chromosome.**

It follows from this, that if unit characters are carried by the genes of the **X-chromosome,** all organisms in which the sperm carry an **X-chromosome,** must necessarily transmit the characters of the **X-chromosome** to the female offspring only, while females can transmit them equally to all offspring. Similarly in those organisms in which eggs may lack one chromosome, the female can transmit characters only to their sons, while males can transmit to their offspring of both sexes. This is the explanation of sex-linked transmission as shown in men who are color-blind. Such men transmit this defect to their daughters, and the daughters can in turn transmit it to all of their sons and daughters.

There are exceptions to this. A usual sex-linked character, such as color-blindness, is sometimes transmitted from father to son directly. This is explained by Bridges as being due to what he terms a "non-disjunction" of the sex-chromosomes in the polar divisions of the egg during the maturation division. In other words, such a non-disjunction may come about by the two **X-chromosomes** in the egg pairing, but then failing to separate, so that either both remain in the mature egg or both are extruded with the polar bodies.

In a study of **parthenogenesis** (virgin-birth) further evidence is brought forth in regard to the function of the X-chromosome.

For example, there may be one maturation division without a reduction of chromosomes. In this case the single polar-body and the egg nucleus will both contain the diploid number of chromosomes. This is quite common in the **Crustacea** and a few other forms.

Or, there may be two polar divisions, after which one of the polar bodies reunites with the egg nucleus. Here, again, the full number (diploid number) of chromosomes are found.

Or, in some forms (**Hymenoptera** and the male-producing eggs of **Rotifers**) two polar divisions really take place, which reduce the chromosomes to the haploid number. If these eggs are unfertilized, **they give rise to males.** Such eggs already have only half the full number of chromosomes. Consequently in their germ cells, in turn, there is no further reduction. The first spermatocyte division in these is really suppressed. If the eggs are **fertilized they produce females.**

In those **Hymenoptera** where there are two divisions, but the chromosomes divide at the equator and not longitudinally, the diploid number is retained and females are usually produced.

Various other evidences of great value and interest will be found in the books on Cytology mentioned at the end of this chapter.

The diagram of the chromosome-cycle of **Phyllaphis coweni** (Fig. 83) will throw light on this subject.

The top group shows a fertilized egg with four ordinary chromosomes and two X-chromosomes. Three lines of descent pass downward from the egg. On the left, this line of descent leads to a female which will produce a sexual egg. The central line of descent leads to a female which will reproduce parthenogentically, and on the right the line of descent leads to a male.

The second and third groupings from the top represent the metaphase groups as well as the diagrammatic anaphases of three eggs, of which the left and middle will produce females, the right a male. In the female-producing eggs, the **X-chromosomes** divide at the equator and not longitudinally; while in the male-producing eggs they pair and separate so that the male has only one **X-chromosome.**

The fifth grouping from the top at the left, is the metaphase group of the first polar division of the sexual egg. All the chromosomes are paired. Below this, the anaphase of the first, and the telophase of the second polar division, leaves three chromosomes in the egg.

The fifth grouping on the right is the metaphase group of the first spermatocyte division with paired regular chromosomes and a single **X-chromosome.** Below this, the diagrams of the first (unequal) and the second (equal) spermatocyte divisions, leading to the ultimate sperm-cell with three chromosomes and a small degenerate cell with two. When the egg and sperm again unite in fertilization, the original six chromosomes are restored and the egg is again as we see it at the top.

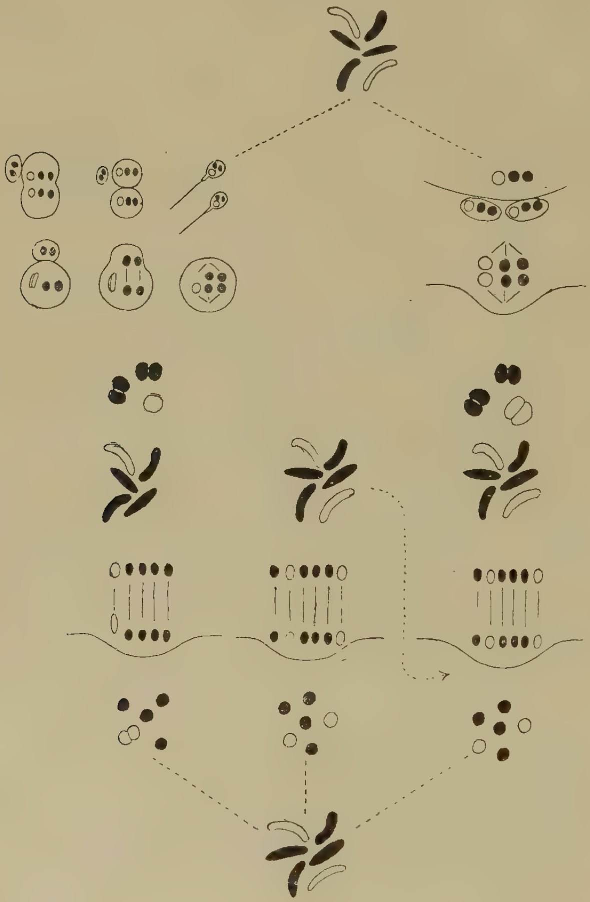

Fig. 83.

Diagram of chromosome-cycle of *Phyllaphis coweni.* See text for explanation. (After Doncaster.)

From what has been said, it can be plainly seen that in all organisms where there is an **X-chromosome**, this extra particle (as it does not divide as do the other chromosomes) must result in some sperm-cells having an even number of chromosomes and others an odd number.

For example, let us say there are 21 chromosomes in the original germ-cell from which the sperm is to develop. One of the newly forming sperm would possess ten and the other eleven chromosomes. The regular somatic number of chromosomes in such an organism would be twenty-two. The egg will, therefore, regularly divide and throw off eleven to obtain the haploid number. Those eggs which are then fertilized by a sperm containing ten chromosomes become males (as the diploid number in such a case would again be twenty-one) and those eggs fertilized by a sperm containing eleven would possess the full somatic number of twenty-two chromosomes and become a female.

This means that in those cases where there are **X-chromosomes**, the odd chromosome never pairs in the maturation division with another chromosome, nor does it produce a tetrad. It simply passes undivided to the daughter sperm.

References:

L. Doncaster, "An Introduction to the Study of Cytology."
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CHAPTER XII.

ANIMAL PSYCHOLOGY

In no branch of study is the student confronted with more difficulties in the way of separating fact from interpretation, and explanation from description, than in the field of Animal Psychology, and this, notwithstanding the fact that Animal Psychology owes its entire value to its ability to explain and not to describe.

The tendency of the human mind to read into an animal's actions the same motives and reasons that cause man to react in a similar manner is difficult to overcome. In fact a definite word, **anthropomorphism,** is in common use among psychologists to describe just this tendency to humanize animals.

Still, the only way we have of interpreting the behavior of an animal must be in terms of human understanding, for we have neither language nor imagery which can bring to us the sensations, emotions, and driving force of an organism so totally unlike ourselves as an insect, for example.

As one writer has said, anger with us is always associated with an increase in heart beat and a more rapid breathing, and our nerves are all "set on edge," but an insect has a totally different set of blood-vessels, an entirely different breathing apparatus and a different nervous system. What are its accompanying sensations when it feels angry? In fact, a wasp often bites off its own abdomen when angry. How can we, when our respective organisms are so unlike, know much about how such animals feel?

Further, all of us have observed that probably most plays and novels hinge their plot entirely on some misunderstanding. If human beings, who have a common language to make themselves understood, are so frequently misunderstood, how much more will we not misunderstand and misread the actions of animals entirely unable to tell us anything in terms which are understandable to both?

It is for reasons of this kind that many throw up their hands in despair and insist that we never can know anything at all about the animal mind, but that if we wish to establish an animal psychology anyway, there is only one way to go about it, and that is, merely to study the behavior in the laboratory under set conditions so that we can learn just how each animal reacts to a given stimulus. Such a method assumes that all animals of the same sex, of the same age, in the same state of health, will always react in exactly the same way when the same stimulus is applied under the same conditions.

We shall go on from this point a little later, after the student understands several important terms.

Objective and **Subjective** are two of the most important. The former is the term applied to all things which come under the senses. That is, a thing is objective when it can be observed and measured in the laboratory. It is anything, in other words, which occupies space. Subjective refers to those things which make no observable difference in space and which cannot therefore be measured in terms of the rule and scale of the laboratory. For example, changes in the mental world, such as thought and feeling, are subjective. In the classic sense, **subjective means the act of mind itself or what is in the mind,** while **objective refers to the matter with which the mind works.**

An illustration of these two terms as they are commonly used comes to mind. Suppose a neurologist were to examine the optic nerve and the optic centers of the brain of a student while the latter is reading a letter. The neurologist could probably tell that the optic nerve and center were functioning, but he could never tell what the latter contained, nor could he see what emotions were called forth in the mind of the student. The movement in the nerve and nerve center would be objective, while the emotional impression made on the student would be subjective.

Not only would the neurologist be unable to observe the emotional impression made upon the student, but he would be unable to tell why certain vibrations which, as far as observation goes, are all alike, should produce sensations of red or green in one case, and another color in another case.

All our emotions, longings, ambitions, thoughts and ideas, as long as they remain mental states, are subjective, while when they express themselves as acts they become objective.

Psychology is the study of the subjective world. The word **Pschyology** (Greek psyche=soul+Logos=discourse) actually means the study of the **soul,** but since laboratory methods have come into existence in psychology, and laboratory men think only in terms of measurable substances, it is commonly said to be the study of **mental phenomena.**

Since the laboratory methods of studying everything objectively under set conditions has made its way into psychology, the workers in this field have become divided into various camps or schools. First, come the **Behaviorists,** who insist that the **results** of mental activity are **actions and reactions to given stimuli,** and it is only these results which can be measured, and which, therefore, may validly be used as data on which to form any theories of the mental life of animals. Second, come the **Introspectionists,** who follow the classic method of antiquity. They insist that the only real way of studying mental life is **to introspect**—to look into our own mental life and try to understand how and why we do what we do under varying conditions. They insist that we must analyze our own thoughts, motives, and emotions, and then if an animal has an organization quite like our own, we may validly assume that it, too, functions somewhat like our own.

Since extremists on any side of a discussion are likely to go astray, it is always best not to confine oneself entirely to following any single group to the exclusion of another. To be fair, one must use anything and everything that will throw light on the problem one is trying to solve.

The word **Mind** is another confusing term. By the older writers it was used to designate the **personality** of an individual. That is, if one say with Descartes "I think" therefore "I exist," the "I" which does the thinking and which does exist is the true personality, the true mind. Or, one may note that it is quite common to dream that one has died and attends one's own funeral. That which can look at its own physical body as the physical co-partner of the true ego—of the individual's personality—is the **mind,** or as the older writers called it—the **soul.**

Not only do we here see a distinction of the ego or personality proper, as **mind,** but we also note that the mind is separate from the thoughts which the mind brings forth. We can, therefore, understand these writers when they tell us that the brain is in turn the organ of the mind, but not the mind itself.

The average laboratory man will have little of this, however. He insists that mind does not exist as distinct from thought and emotion. He means by mind the whole **"stream of consciousness"** of the individual—all thoughts such as one has ever had, plus all one's emotions, such as pleasures and pains—**accumulated experiences of the individual,** in other words.

The laboratory men do, however, admit two divisions of this mental life, namely, **consciousness** (awareness) and **feelings** (emotions or affections, such as pleasure and pain).

The student can understand these two divisions easily if he will think of breaking a bone in his body. It is one thing **to know** (be conscious of) that the bone is broken, and another thing entirely **to feel** the pain it may cause.

The idea of a difference between the mind and the physical body containing it, leads us to note the distinction between **mind and matter.** Those who accept this distinction are called **dualists.**

Great conflicts have been waged by the learned of all times as to which is the more important of the two—mind or matter—and which was first upon the scene of existence. Some have contended that mind (spirit) came first, and this, then, was the cause of the physical universe (matter). Such contenders are known in philosophy as **spiritualists.** Others contended that matter was first on the scene, and that mind was late in its arrival, because it is only an emanation of some kind from the physical. That is, mind is something like the secretion from ductless glands which we know little about, but which we know to exist. Such men are called **materialists.** Yet another group insisted that as mind and matter are always together, neither may be given the preference. Both are different sides of the same coin. Each thought-wave is always associated with a nerve-wave of some kind, and neither can exist without the other. Such men are called **monists.** It will be seen that the term "monists" is applied to this group because they do not accept a dualism in life.

These different groups of contenders attack psychological problems with different prepossessions. The spiritualist is likely to call himself an **interactionist** in psychology, the materialist a **behaviorist,** and the monist a **parallelist.**

As it makes a profound difference to a patient as to which one of these theories his physician holds, the student must know what each term means or he will be totally unable to pass judgment on the many and conflicting discussions which are ever coming before him.

The interactionist holds that the state of mind of an individual can and does influence his physical being and **vice versa.** An example of this is a man worrying over financial losses, whose body becomes run down until disease clutches him.

The behaviorist insists that only a definite physical reaction, measurable in the laboratory, is valid data on which to base a scientific conclusion, and that until the individual mentioned above shows a definite measurable reaction, there is no change which we as scientists can use or accept.

The parallelist, insisting as he does that both the mentality and the physical organ which is associated with it are different sides of the same thing, must necessarily consistently claim that the mind is totally unable to influence the body and the body totally unable to influence the mind. In fact, one of their prominent writers says that one may as well expect a piece of beefsteak put into a sausage machine to come out a moonlight sonata as to expect either body or mind to influence each other.

It is therefore only the interactionist who can consistently speak of **nervous and mental** diseases, and who can consistently use both physical and psychic remedies.

At this point we may consider what is commonly designated as **structural** and **functional** psychology.

Structural psychology concerns itself with (1) the general organization of an organism, (2) the general organization of its nervous system, and (3) the organization of the specialized nerve parts such as the eye, ear, nose, etc.

Functional psychology is interested in (1) the general way an organism reacts (discrimination), (2) whether the organism can modify its action (docility), and (3) in how many ways and in what way its behavior will vary (initiative).

Again the student must be cautioned not to let one side of a problem cause him to discard much that is of value in opposing schools of thought.

Just as those who are primarily interested in nothing but anatomy are likely to leave out important functional causes in a disease, so those primarily interested in physiology are likely to forget the structural elements which may contribute points of tremendous importance.

All schools of science have been drilling into the student the supposed "fact" that "Structure determines Function," but since the very recent work of Carey, who converted unstriated bladder-muscle of a living dog into living heart-muscle by simulating heart conditions in the bladder, we must insist that function has just as important a part in changing and determining structure as structure has in determining function.

However, we must not forget that even in the case just mentioned, the substance to be changed was already present and must have possessed the potentiality of change before it could be worked upon.

With this introduction we can the better understand the two ways in which the study of comparative psychology is approached by the modern laboratory worker. **First,** we may take a highly developed individual, such as man, and after analyzing his mental-world, apply the knowledge thus gained to the lower forms, or

Second, we may follow up, step by step, the increasing learning-ability on the part of all phyla of animals, beginning with the unicellular and passing upward through an ever-increasing scale of ability.

It is this second method which seems to have found most favor with animal psychologists.

But, in reading works on animal psychology, one is always confronted with a great confusion of terms. In fact, one finds here the same difficulties that confront the student in any of the biological sciences. The first workers in all these fields were philosophers, and were interested primarily, and sometimes only, in the human family. The terms, therefore, which these men used, although worked out with great precision, applied only to man.

The newer writers took many of the older labels and placed them on new bottles, so to speak. This has caused a world of confusion, not only to new students, but to many well versed in language and literature.

Such words as Mind, Intelligence, Reason, Memory, Consciousness, Sensory or Associative Memory, Instincts, and Reflex Actions, are some of the terms which the student must use, and which have many conflicting meanings in modern literature. It is imperative that the student obtain a clear and concise definition of these terms and use them only in this restricted sense. Then only can he understand the meaning which different writers assign these words, and then only can he know whether they are calling other things by the same name or giving different names to the same thing.

We shall have to speak of **Instincts** immediately, so it is well to begin with this term. **Instincts** are defined as **inherited tendencies in an organism which cause protective reactions when harmful stimuli are applied.** For example, a frog, even after both cerebral hemispheres are removed, will still scratch the part of its body to which a drop of acid is applied, and it will even snap at and swallow a fly if placed on the tip of its nose. Again, a fly will walk, fly, and clean its legs and wings, after its head is entirely removed, and the writer has kept a decapitated cat alive for many hours by artificial respiration and caused it to perform many instinctive actions such as scratching itself, waving its tail, etc.

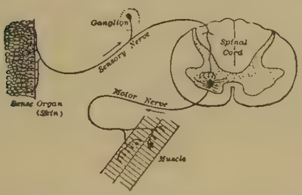

Fig. 84. Diagram of the path of a simple nervous reflex action.

In order to understand Reflex Action, it is first necessary to know the meaning of a **Nerve Arc** (Fig. 84). This latter is merely the entire nerve-path over which an impulse passes to a nerve-center and out again to a muscle cell. It must, therefore, consist of the nerve-ending of a sensory nerve (receptor) through which the impulse is received, the sensory nerve-fiber which carries the impulse to the nerve-center to join at this point with a motor-nerve fiber which in turn carries the motor impulse to the **motor-nerve-ending** (affector). This motor-nerve-ending is always located in some muscle fiber. The textbooks often speak of a nerve-arc, as **"a perception with a motor impulse."**

A **Simple Reflex Action** is one that passes over such a simple nerve-arc without first passing to the higher nerve-centers, or, we may say, one which does not come into the **consciousness** of the individual in whom the action takes place. Such a Reflex Action is, therefore, purely physical. There is no need of assuming any mental state or sensation as an accompaniment.

When an individual is born, his nerve **arcs are** set in some form or another, so that with one individual the same stimulus will cause quite a different reaction, than it will in another. But, just because these nerve-arcs are **set** in the way they are, the same nerve-arc will always react in the same way to the same stimulus, if all other conditions are equal. For example, a child may have grown accustomed to saying "I is" for "I am" and have said it so often that it finds it very difficult to correct itself. Now, if we constantly force the child to use the form "I am," the particular nerve-arc which carried the "I am" reaction will become relatively stronger than the one which carried the reaction "I is," and then, and not until then, does the latter phrase become a sort of second nature of the child.

So, too, a puppy that has the vicious habit of snapping at passers-by, can be made to react differently by giving him a whipping several times, immediately after he does the undesirable act.

In both these cases memory enters, but only a simple **sensory memory (association memory)** which has little to do with any **thought** The impulse (inner stimulus) in the puppy to snap, is great, and so the "snapping nerve-arc" carries the impulse and the snapping is done; but the punishment which has been meted out has set up **an impulse of an opposing nature**, and as soon as this latter becomes the stronger impulse, the puppy has been **trained.**

We may say in this case, that the puppy has the desire to snap, and the nerve-arc which carries this snapping-impulse begins to function; but the whipping has caused a new nerve-arc to function at the same moment, so that a third nerve-arc, that of **inhibition**, comes into play and the animal does nothing. This is quite similar to the reaction of persons in hypnosis. Here an individual is told he cannot bend his arm. The impulse not to bend the arm is just as strong as the one to bend it, and so no movement takes place.

An **impulse** is defined as an **inner stimulus.**

It is well to bear in mind the foregoing paragraphs as these show the possibility of two opposing impulses and even two opposing reactions taking place at one and the same time over different nerve-arcs. Often we read of lower organisms possessing discriminating powers of various kinds which can be interpreted in quite different ways from what the writer of such an account would have us believe. We need only remember that there can easily be one set of nerve-arcs functioning for the acceptance of food and another set for the rejection of it, so that it depends on which set carries the stronger impulse as to whether the animal accepts or rejects the food. It is by no means necessary to assume any **discriminating ability.**

There are also **Complex Reflex Actions** making use of several nerve-arcs,. sometimes often forming regular chains of reactions. In these cases, the result of one stimulus sets up another, and so on. In fact we call such continued setting up of stimuli **reflex chains.** As an example we may refer back to the frog whose cerebral hemispheres have been removed. If we place a fly on the tip of its nose, that stimulus sets the "snapping" nerve-arc functioning. Then as the fly is taken into the mouth, a new nerve-arc causes a swallowing impulse, which sets up reactions of still other nerve-arcs which in turn cause the digestion glands to pour out digestive substances.

It will be noted that such reflexes are quite **useful** to the animal, and it will be remembered that our definition of instinct called attention to the **protective** value of inherited nerve-arc actions.

Instincts may be **deferred.** That is, they may not be observable at birth, but come forth only later in life when various glands begin to pour out secretions which affect many parts of the body.

It is often stated that instincts are the "inherited habits" of the individual's ancestors. This was Lamarck's idea. But this cannot be, because many animals lay their eggs before they themselves have developed the later characters, which the offspring possess. Consequently the young would have to inherit a habit that the parent was going to form later. This is somewhat like saying that because both a mother and her daughter are divorced, the daughter inherited her divorce from her mother.

While instincts are made up of reflexes, the reflex proper is said to affect only one part of the organism while instinct affects the entire body. That is, we should say the winking of the eye, when danger threatens, is **reflex**, while running way from the danger is **instinctive.**

Instincts really consist of inner driving forces which make the animal possessing them restless until the instinctive act is performed. However, we must remember here also that just as with the impulses already mentioned, there may be conflicting instincts. In such cases the stronger will come forth. Or both may be equally strong, so that no action at all will take place.

Recent psychology often speaks of **tropisms**. As we have seen from our study of former chapters, a tropism is a movement of some kind on the part of a living organism. Those who wish to interpret all action of living organisms in terms of physics and chemistry are fond of using this term. Such men prefer to cast the term "instinct" to the four winds of heaven and explain everything in **physico-chemical terms.** They insist that a caterpillar climbs to the end of a twig on account of the chemical change in its body that is caused by hunger, let us say. New chemical molecules and adjustments are forming, and this makes one part of the body lighter than another, so that the laws of physics enter and the heavier part will be followed by the lighter in going downward, or a chemical affinity of some nature will draw the chemical substance of the animal toward it. After having eaten the tiny bud on the twig, a new chemical change takes place and so the animal must, whether it will or not, obey the next chemical and physical change and descend from the twig.

Dr. Vernon Kellogg, recently in this connection, called attention to a scientific friend who explained to Dr. Kellogg that the reason he took a corner seat in a restaurant was due to a primeval impulse which made him want to have his body in close contact with the wall. But, as Dr. Kellogg says, the reason he chose that particular seat was because he had made an appointment to meet a friend there.

As the principal test of an animal's mental ability is the rapidity with which it **learns**, we must know what Learning means. **Learning** means the ability on the part of a living organism to vary its actions according to some definite plan which will show that it has profited by past experience.

In this connection one is also confronted with difficulties as in other fields. Suppose one is attempting to see whether an animal can distinguish between colors and then learn to go to one hue rather than to another. Suppose now, that the animal does not show any more inclination of going toward one color than toward another. This by no means proves that the animal cannot distinguish, or is unable to learn, that there are two colors. It may mean nothing more than that colors make so little difference to the animal that there is no reason (motive) for his choosing one rather than the other. In such an instance the animal's reaction to both colors would be identical, and one could prove little or nothing from its behavior.

Another animal may be thought unable to learn because it tries a problem a few times and then ceases to react at all to the stimulus. This may be due entirely to fatigue on the part of the organs used, and not to inability to learn. That is, the nerve receptors may become dulled or tired by new stimuli which are foreign to the animal in its native career.

Or again, some sensation may be pleasant to an animal only if secondary factors are present, such as the taking of food only when hungry or when the body is in good health. But surely the rejection of food does not mean that the animal either can or cannot discriminate between foods. We often will not eat one kind of food, while another is relished, or we often will just as readily eat ice-cream, candy, or fruit, and show just as much desire for the one as for the other, but this certainly does not mean that we do not know the difference between these three types of edibles.

Then, too, the state of health makes a tremendous difference in what an animal will choose. Dogs and cats eat certain plants at certain times but at other times they will not touch them. But do they not know the difference between these plants and other food?

Then, too, an animal may be trained to do certain things, but suppose it does these things without having been trained. Can one not argue as well that the animal merely stumbled upon doing the act, and then doing it often, the nerve-arcs became **fixed** and the animal can no longer help itself? It is now a **habit.**

Habits are but acts performed by fixed nerve-arcs.

The question may arise as to what difference there would be between psychology and physiology if all we are to study consists of nerves and reactions. Really, there would be no difference **in content** of the two sciences, the difference would consist in **emphasis.** The psychologist lays stress on emotions, feelings, etc., and the physiologist on the simple observable reaction which follow a given stimulus. The psychologist, in other words, wants to know how the animal feels and what it has in its consciousness when a stimulus is applied and its actions are changed.

We have seen in our study of past chapters that the unicellular **Paramoecium** has only two simple reactions, namely, a backward and forward movement, while the vertebrate frog can move in many and varying ways in order to get out of harm's way. Probably all animals can **learn.** That is, they can be taught to make some change in their behavior, but the rate of speed with which they can learn probably becomes greater as we ascend from lower to higher phyla. The same may be said of the complexity of the problems to be learned.

All animals and children when left to themselves learn whatever they do learn by what is called the **trial and error** method. This simply means that they try something and if this is unpleasant or painful, they try something else. Contrariwise, if a reaction produces pleasure, it is done again and again until it becomes a habit.

All learning, no matter what it may be, **must, however, be based on instinct** in its widest sense. That is, the problem presented must be something which can be solved by making use of some instinctive behavior of the animal upon which we wish to experiment. For example, a cat can be placed in a closed box in which there is a lever, which, when pressed, will open a door. Now, cats are excitable and when excited will begin to leap about. This is an instinctive action. If, while leaping about, the animal strikes the lever and the door opens, it can be trained, by enclosing it often enough in the same or a similar box, to press the lever without going through the leaping first.

Learning, then, really means **profiting by past experience.** But no profiting by past experience is possible unless such past experience is remembered. Now, such memory by no means must be a definite thinking out of a past event and then sitting back and saying "I will" or "I will not do this again." Most physical experiences, even in man, are merely non-conscious functioning of nerve-arcs. Neither men nor the lower animals do any **thinking** in regard to these simple or complex-chain-reflex-actions. It is a mere association of one stimulus starting another and is called, as already stated, **sensory,** or **associative memory.**

There may, or may not, be **an awareness** of doing an act at the time it is being done. That is, there may be consciousness not only of the fact that an act is being performed, but there may also be an awareness of pleasure and pain, accompanying it, though there is little proof that a **definite thought**—that is, **reasoning**—is performed, and that it is then due to such reasoning that changes of action are made. These learning acts are in all probability due only to sensory memory.

An example comes to mind. We have all heard some one tell of a horse that knows when Sunday comes, that being the only day when the animal does not come out of the stable to be harnessed as soon as its master appears.

But does this show that the horse can count up to seven and has a sort of mental calendar on which he checks off the days? By no means! All it may mean is that if a horse works six days in the week, there is a certain feeling of tiredness which has become associated with it, just as a blind man can tell by his "feeling" how many blocks he walked and where it is time to turn without counting the blocks.

We can then conclude that all animals may be conscious to some extent; that is, they may be **aware** of their actions, although this has nothing to do with reasoning—with thinking.

The veteran experimental psychologist, the late Professor Wm. Wundt, said, "Animals never think and humans but seldom," and most animal psychologists hold to this dictum, if, by "reason" is meant **true thinking,** that is, **a weighing of two or more sides of a problem and then by a definite mental act decide or conclude what is to be done.** In other words, thinking means to use **abstract ideas** and to **form conclusions.**

There are many writers who mean by the term "thinking" only an ability to profit by past experience, so we must always find what an author means by his terms before we attempt to pass judgment on what he says. Others likewise speak of "Intelligence" which **should mean** only the ability to think, as any associative memory. This is really placing old labels on new bottles and is very confusing to the student who wishes to know both the past and the present of his science.

The desires of the different men in animal psychology must also be taken into consideration when reading their respective works. There are those who wish to show that there is no real difference between man and the lower animals. These insist that man has nothing distinct from the lower animals except language, but that man's seeming difference in the mental world is only a little greater development of animal characteristics. Language by them is often said to be the cause of man's greater mental ability in that he can by this means write down his findings so that others may profit by them.

Those who hold that man is something separate and distinct from the animal, call attention to the fact that language but expresses thought, and one must have thought before he can develop a language, rather than language being the cause of thought. These men also insist that there is no proof that any animal has ever "reasoned" out a problem in the way mentioned in an earlier paragraph, and therefore no animal lower than man can be said to have any "Intelligence" in the classic sense.

These latter men would say that hundreds of thousands of cats, dogs, and even apes (which are considered the more intelligent animals) are very fond of warm places. Such animals have lain before hundreds of thousands of open fires and enjoyed the warmth. They have seen their masters keep the fire aglow by placing fuel upon it, and yet not in a single instance has any animal drawn the very simple conclusion that it is the fuel which keeps the fire going, and has, therefore, placed (without being taught), a single stick of wood on the dying embers.

Not only this, the child when it grows up teaches others, and our schools and colleges are all arranged for the sole purpose of making a young man and woman at an early age know what it would take a very old person centuries to learn by personal experience. No animal is known to teach another a trick which it itself has learned from a third individual, unless, of course, the act is instinctive and would have been learned anyway.

Whether one thinks of man as but a more highly developed lower animal, or whether one looks at man as a being apart, all agree that, man can reason, whether he often does or not. All agree that man has larger brain-hemispheres of finer texture than organisms on a lower scale; that he has an upright posture and a more delicate hand; that he can use tools, and has the foresight to be able to raise his own food and to live in cold climes by understanding the use of fire; and above all that he is set apart from other creatures not only in having a language, but in also having a knowledge of what he should and should not do—in other words, that he has a **moral sense.**

So, too, all are agreed that the **trial and error method** of learning shows infantile or animal intelligence and not human intelligence. All education, all colleges and universities have been brought into existence to present **principles,** that is, to present a mental and cultural gauge, so that each individual need not try out every detail of experience for himself; but, by learning the principles and laws which govern nature, he can sit back and "figure out" or " reason out" whether a given conclusion can or cannot be true.

This is just as workable in the political and religious world as it is in the scientific. Here is shown the difference between the educated and the uneducated man. One must not feel hurt or surprised if an educated man, knowing his principles and his laws, laughs at one who proposes a problem or a solution of a problem which can be seen to be erroneous immediately. The uneducated man cannot understand or see this until it has been tried and found unworkable.

From what has been said in this chapter, if we wish to be sure that we are right, we must be sure of what a writer means by his terms; we must be sure that we are not reading too much of our own thoughts into an animal's acts; we must be sure that we are consistent in our interpretations and that if we explain an animal's behavior in terms of tropisms that we must also interpret man's in much the same way; we must insist that the observer who is attempting to convince us that his theories are correct, has a scientific training and knows how to distinguish all these things of which we have been speaking. That is, he must be able to separate fact from inference. We must insist that he be intimately acquainted with the habits of the animal he is discussing, so that he will not assume, for example, that an animal, like many insects which have an instinctive impulse to cover up obstructions, is showing great intelligence when it covers up a minute stream and thus forms a bridge and crosses it; we must insist that he know the past experience of the particular animal he is discussing so that he will not confuse an associative memory with true intelligence; we must insist that he has no personal affection for the animal and thus wants to make it "show up" well; and lastly, we must insist that he do not let his desire to tell a good story gloss over important details and leave out others.

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CHAPTER XIII.

INTERMEDIATE ORGANISMS

One of the interesting findings of biology is that it is sometimes impossible to distinguish between certain plants and animals in some of the lower forms. The classic example of this is the plant-animal **Haematococcus** consisting of a single cell and moving about by flagella.

It will be remembered that **Euglena viridis** has chlorophyl in the body and is classified as an animal. One of the great and outstanding characteristics of plants is that most of them possess chlorophyl **if they grow in the light,** and that they are capable of manufacturing their own food by virtue of this fact. (See Chapter on the Chemistry of Living Matter.)

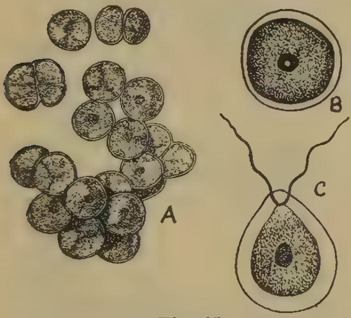

Fig. 85.
A. Pleurococcus.
B and C. Haematococcus Cells.
(Greatly magnified.)

Pleurococcus (Fig. 85) commonly studied in the laboratory is a close relative to **Haematococcus.** It is a one-celled organism found commonly on the north side of trees, moist rocks, and wooden fences, dull green in color, and powdery when dry. When moist it becomes brighter in color and slimy to the touch. It is found in practically every part of the world on the shady and moist sides of the objects mentioned above.

Under the microscope it is found that this substance consists of thousands of tiny single-celled organisms to which the name of **Pleurococcus** has been given. There is a definite cell wall and a nucleus. The chloroplast, however, obstructs a view of the nucleus in the unprepared cell. The organism reproduces by simple fission and has a tendency to form clusters or colonies usually of from two to ten or twelve cells. When this occurs the cells assume a more or less irregular shape due to the pressure of the adjoining cells. The nucleus lies near the center of the cell and contains one or more nuleoli. The network of the nucleus can also be distinguished.

In the cytoplasm will be found the chlorophyl-bearing organ or region called the **chloroplast.** Due to the chlorophyl this will appear bright green, but if the cell be placed in alcohol the chlorophyl will be dissolved out leaving the chloroplast grayish. It is important to note the distinction between the chloroplast, which is a **living organ** of the **protoplasm, and the chlorophyl,** which **is simply the green pigment** contained in the chloroplast.

Photosynthesis.

In the final analysis every particle of food an animal eats must come from and through the plant world. For example, when man eats a piece of steak, the animal from which it was taken lived either directly on plants or on other animals which fed on plant-life.

Here it is well to appreciate the interesting way Nature has of keeping a sort of balanced quantity of all needed organisms, for the meat-eating animals or **carnivores** do not allow an overproduction of plant-eating animals or **herbivores**, and are prevented from multiplying too rapidly by parasites in their own ranks, while much of the vegetable world is saved because animals eat each other.

The thought of these facts has led to the statement that the important thing in life was to get enough to eat and to prevent one's self from being eaten.

The plants manufacture their own food from the substances they can extract from the surrounding soil and the air. Plants are therefore not dependent upon other animals or plants for their food as animals are. Those organisms dependent upon other living organisms for their food are said to be **heterotrophic** ( ) in nutrition while those which can manufacture their own food are said to be **autotrophic** ( ) in nutrition.

But only those plants which possess chlorophyl are autotrophic. Therefore **fungi, molds,** and **most bacteria,** which **are plants,** but which **have no chlorophyl,** are **heterotrophic**; and, being obliged to live upon other organisms, they are parasitic ( ) or saprophytic ( ).

Chlorophyl is either contained **in a chloroplast,** as already stated, or, in the simplest form of green plants, it is **scattered throughout** the protoplasm. Chemically "chlorophyl is a complex compound of carbon, hydrogen, oxygen, nitrogen, and magnesium; its probable empirical formula is given by one investigator as $C_{54}H_{72}O_6N_4Mg$. While not a constituent of chlorophyl, iron is always present in the chloroplast and seems to be essential to chlorophyl formation. Either in solution or in the living plant chlorophyl absorbs part of the light which falls upon it." The energy of the light thus absorbed by the chloroplast is what enables the plant to perform its work. As light is required this process goes on only during the day.

"The materials from which carbohydrate food is manufactured by green plants are two in number, carbon dioxide and water. Carbon dioxide is present in the atmosphere in the small but constant concentration of about 3 parts per 10,000 parts of air, and is therefore readily available to such plants as the **Pleurococcus.** Water is absorbed directly from the substratum through the cell wall into the protoplast. The carbon dioxide taken in is dissolved in the water in which it is readily soluble. While the exact steps in the process of formation of carbohydrate foods from these substances are not yet clear, the essential facts are well established. The carbon dioxide and water are partially or completely reduced to their elements, which immediately recombine to form a monosaccharide sugar (probably dextrose) with the freeing of oxygen. These two processes are represented by the reaction $6CO_5+6H_2O=C_6H_{12}O_6+6O_2$. The oxygen is given off into the atmosphere through the cell wall. The sugar is the primary food of the plant, being the principal material used in the synthesis of other foods and in the processes of metabolism. When it is produced in excess of the immediate requirements a further reaction takes place by which some of the water is eliminated and the sugar is "condensed" into starch; this reaction is $n(C_6H_{12}O_6)=(C_6H_{10}O_5)n+n(H_2O)$.

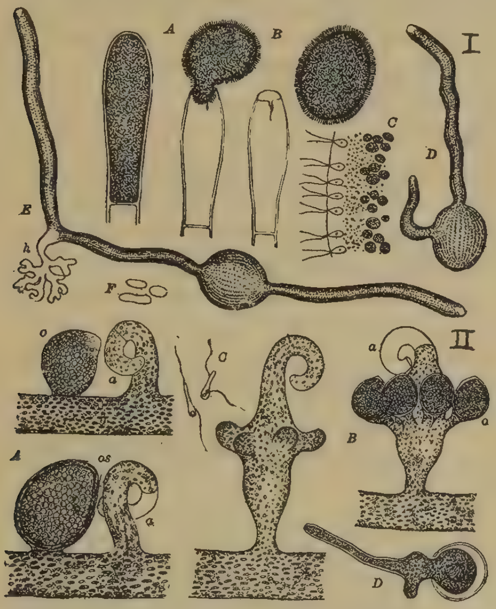

Fig. 86.

I. Asexual Reproduction of the Green Felt (*Vaucheria*).

A, formation and discharge of the large, many-ciliate zoöspore from the terminal sporangium; *B*, the zoöspore showing the ciliated surface; *C*, section through the surface of the zoöspore showing the pairs of cilia above the nuclei and the layer of plastids beneath; *D*, germination of zoöspore; *E*, young plant of *Vaucheria*, the two filaments having arisen at opposite ends of the zoöspore, one having developed an organ of attachment or holdfast *h*; *F*, a group of plastids, the lower in process of division. (*A*, *B*, after Götz; *C*, after Strasburger; *D*, *E*, after Sachs.)

II. Sexual Reproduction of the Green Felt (*Vaucheria*).

A, *Vaucheria sessilis*; *o*, oögonium; *a*, antheridium; *os*, the thick-walled oöspore, and beside it an empty antheridium; *B*, *Vaucheria geminata*, a short lateral branch developing a cluster of oögonia and a later stage with mature oögonia *o* and empty antheridium *a*; *C*, sperms; *D*, germinating oöspore. (From Bergen & Davis "Principles of Botany" by permission of Ginn & Co., Publishers. *C*, after Woronin; *D*, after Sachs.)

"This starch is deposited in the chloroplast as granules or "starch grains" and forms a reserve food supply for the cell; in green plants kept in darkness the starch grains soon disappear and reappear only after the plant has again been in the light for a considerable period of time. In some plants, e. g., **Vaucheria** (Fig. 86), the excess food is stored in the form of a fat or oil, but it is probable that here also the first food formed is a sugar.

"This process by which carbohydrates are manufactured in green plants is called **photosynthesis**; its essential features are summarized as follows: The materials used are carbon dioxide and water; the energy is obtained from sunlight absorbed by chlorophyl; the chloroplast by the use of this energy brings about a chemical synthesis of the materials, resulting in the freeing of oxygen and the production of a sugar, some of which is usually transformed into starch and stored in that form."

There are **mineral substances** also necessary for the plant to carry on its life-processes such as magnesium and iron. Nitrogen, potassium, phosphorus, calcium, and sulphur are also required by most plants, although it is to be understood that there are very minute quantities of these in so simple a plant as **Pleurococcus.**

The process by which proteins and fats are built up is not known in detail, but it is supposed to be due to the action of enzymes. The fats occur in **Pleurococcus** at those times when the plants become dry and are inactive or in a resting condition. At such times little or no starch is formed while fats are present in quantity.

YEASTS

The **Pleurococcus** just studied, though a simple single-celled plant, is quite complex when compared with a yeast cell. The yeast cell is merely a small mass of granular cytoplasm with various vacuoles scattered about. These vacuoles must not be mistaken for nuclei. Often there are little **buds** (Fig. 87) on the side where a new cell is forming, and sometimes three or four cells will form surrounded by a single wall, in which case the outer wall forms an **ascus** ( ), and the cells contained therein are **ascospores.**

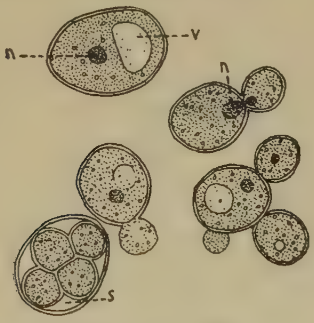

Fig. 87. Yeast Cells.
n, Nucleus; *v*, vacuole; *s*, ascus.

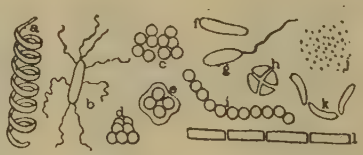

Fig. 88. Various Forms of Bacteria.
a, *Spirillum*; *b*, *Bacillus typhosus*; *c*, *Staphylococcus*; *d*, *e*, *j*, *h*, *Micrococcus*; *f*, *k*, *l*, *Bacillus*; *g*, *Psuedomonas pycocyanea*; *i*, *streptococcus*. (From G. Stuart Gager's "Fundamentals of Botany," by permission of P. Blakiston's Sons & Co., Publishers.)

The nucleus may be shown by special staining processes.

Yeasts have been called **organized ferments** because fermentation is actually associated with the life of the yeast-cell. That is, there are enzymes **within** the cell (intracellular) which **act through the living protoplasm** which produced them. They are not poured out as in the saliva or the pepsin (extracellular).

This power of producing fermentation possessed by yeasts is still retained even though the plant itself be killed with alcohol, ether, or acetone. So, too, the bacteria which cause lactic acid in milk may be apparently killed, thus losing their power to perform any of the normal vital actions such as growing and dividing, and yet be able to produce lactic acid.

Yeast reproduces **by budding** [(also called gemmation) ( )].

A valuable study by the great French bacteriologist, **Louis Pasteur,** has shown that various inorganic substances could be made into a fluid and if the yeast cells were placed therein they could utilize it for growth and reproductive purposes. This ability to use and manufacture new substances from **wholly inorganic** matter sets the yeasts apart as being a sort of intermediate grouping between even the lowest plants and the inorganic world.

Yeasts must have oxygen, however, to carry on their work, the **anaerobic** ( ) bacteria are the only exception among living organisms in not needing oxygen.

It must be remembered that the yeast cell is an organism and is already existent, only making use of these inorganic substances by converting them into proteins and carbohydrates, by virtue of the chemical enzymes within the yeast cell itself.

Yeasts work at temperatures from 9 to 60 degrees C. When fermentation takes place, as in bread, the temperature is raised during the fermentation process by the release of energy.

Yeast secretes an enzyme which is a sugar ferment. This enzyme may, for example, convert starch into sugar, although yeast "utilizes only about 1% of the sugar, and decomposes the remainder into carbon dioxide and alcohol. The reaction of the fermentative decomposition may be expressed as follows:

$$\underset{\text{Sugar}}{C_6H_{12}O_6} = \underset{\text{Alcohol}}{2C_2H_6O} + \underset{\text{Carbon dioxide}}{2CO_2}$$

It is the production of these two by-products that makes yeast commercially important. Yeast produces the same reaction in the sugars of cider and wines, and in the metamorphosed starches of the cereal grains, that are chiefly used in industry in the production of alcohol. The carbon dioxide is also utilized in the making of bread. Yeast is mixed with the dough, and, fermenting in it, evolves the carbon dioxide gas, which "raises" it, making it porous, and improving its digestibility and flavor.

"If a little fresh yeast be sown in a bottle of Pasteur's solution (or even in a 15% sugar solution made with tap water, which will be likely to contain enough of the mineral salts for considerable growth), and kept in a moderately warm place, within twenty-four hours abundant growth will be evidenced by the increasing turbidity of the liquid, and by the taste of the alcohol in it and by the odor of the escaping carbon dioxide* arising from it. It may be demonstrated by examination of a drop of the fluid with the microscope."

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*A simple chemical test of the presence of CO_2 in the escaping gas may be made by thrusting a glass rod with a drop of lime water suspended on it into the mouth of the culture bottle. The calcium oxide (CaO), of which lime water is a solution, readily unites with free carbon dioxide to form a white precipitate of calcium carbonate $CaCO_3$ ($CaO + CO_2 = CaCO_3$) which may be seen to form in the drop.

BACTERIA

It is common to hear discussions regarding **germs** of various kinds. Such discussions usually pertain to all those plants and animals which are likely **to cause disease. Bacteria,** however, refer to very minute **plant organisms** classified under the chlorophyl-less **fungi (mycetes),** under the general grouping of **schizomycetes** ( ).

While **most diseases** are probably due to, or associated with bacteria, **very few bacteria,** relatively speaking, **cause disease,** the great majority of them being of undoubted value to other living organisms.

There are **three general shapes** after which bacteria are named. The **bacillus** is **rod-shaped** (b, f, k, l, Fig. 88), the **coccus** (c, d, e, f, h, Fig. 88), (sometimes micrococcus), is **berry-shaped** or spherical, and the **spirillum** is **spiral-shaped** or merely curved something like a comma (A, Fig. 88). Bacteria may be so small that only many thousands together form a spot sufficiently large to be seen under a high power microscope, or they may be of relatively large size. That is, they vary from less than 1 **micron** (the measurement used in microscopy, meaning 1-1000 of a millimeter, or 1-25000 part of an inch) to 30 or 40 microns. It has been estimated (Migula) that there are 1272 distinct species of bacteria.

Not only do bacteria vary according to shape, but as to their method of growth under varying conditions of temperature and surrounding substance.

Bacteria may possess cilia or flagella and move quite rapidly. They reproduce by simple binary fission. The spirillum and bacillus divide at right angles, usually lengthening slightly before division. Cocci may divide in different planes and various names have been assigned to them on this account. If they divide into two parts but remain attached they are called **diplococci** ( ). If they continue dividing in one plane in this way but remain attached so as to form chains they are called **streptococci** ( ), if they divide in two

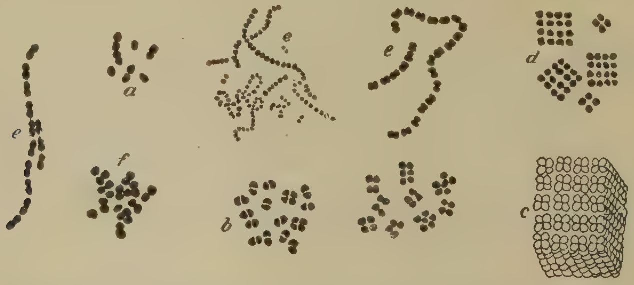

Fig. 89. Various Groupings of Spherical Forms of Bacteria.

a, Tendency to lancet-shape; *b*, coffee-bean shape; *c*, in packets (sarcina), *d*, in tetrads; *e*, in chains (streptococcus); *f*, in irregular masses (staphylococcus). Magnified 1000 diameters. (After Flügge.)

planes they are called **staphylococci** ( ), and if in three, **sarcina** ( ). (Fig 89.)

Sometimes the protoplasm of bacteria breaks up into a number of bodies within the cell. These bodies are called **endospores** ( ). The value of this breaking up is supposed to be similar to that of encysted amoeba; namely, to permit the organisms to await some more favorable feeding period and environment. During this spore state bacteria are very **resistant.**

The **sterilization** of various substances in the laboratory takes sporulation into consideration, so that when a substance is to be sterilized, it is placed in a temperature of 50 or 60 degrees C. for **several days in succession, rather than at a higher temperature at one time.** This permits the spores to germinate. As spores are hard to kill while in the spore-state, but readily succumb when placed in a 50 to 60 degrees C. temperature after germination, it will be seen that this intermittent sterilization is the best method so far known.

"Fischer divided bacteria into three groups, according to the nature of their metabolism. (1) Bacteria which are like the green plants in requiring neither organic carbon nor organic nitrogen. These are the so-called prototrophic bacteria, which possess the remarkable property of being able to build up both carbohydrates and protein out of carbon dioxide and inorganic salts. (2) Bacteria which need organic carbon and nitrogenous compounds. These are called the metatrophic bacteria. (3) The paratrophic bacteria which live as true parasites and can exist only within the living tissue. This group cannot manufacture its own food and is like other animals in this respect. The metabolism of bacteria may then show all of the phases already described for green plant cells and for animal cells as well as certain additional phases. The food is absorbed directly through the cell wall and is as varied as is their habitat. There seems to be no form of organic substance living or dead that may not serve as a source of food supply for bacteria, so that the enumeration of their foods becomes practically impossible. A special phase of the metabolism of bacteria is illustrated in their relation to nitrogen compounds. Nitrogen in an uncombined state cannot be used as food energy by most plants. It is obvious that the amount of ammonia, nitrites, and nitrates would soon become exhausted unless there were some way of supplying more of the nitrogen compounds. Many of the soil bacteria are prototrophic in habit and carry on the important work of combining the free nitrogen into a form that can be used by other organisms. The several nitrogen combinations are effected through the agency of several kinds of bacteria. There are also bacteria which live in the roots of certain plants, like clover, beans, and peas, which are able to utilize the nitrogen of the air. All of the higher forms of plants and all of the animals are dependent upon microscopic bacteria for their nitrogen. It would be very strange if the character of metabolism which is so fundamental in living things should be essentially different in bacteria; it probably is not, and so the usual steps in assimilation and dissimilation may be assumed to take place in bacteria. During this process enzymes are utilized and toxins produced."

Bacteria increase with marvelous rapidity by becoming larger in size, followed by a division of each organism into two. If each of these divide every half hour, in twenty-four hours a single bacterium will have become something like 17,000,000 individuals. It can be seen quite readily that such a tremendous increase in so short a time means that vast quantities of food must be at the bacteria's disposal, or the organisms themselves must die. If they are then in the body of an animal, the effects of the poisons produced by their dead bodies may be an important factor in injuring the host.

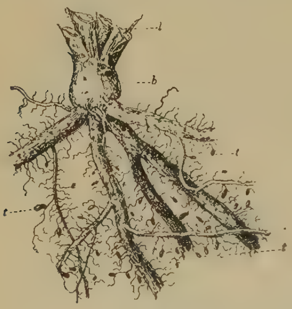

Fig. 90. Tubercles (Galls) on the Roots of Red Clover.
1, section of ascending branches; *b*, enlarged base of stem; *t*, root-tubercles containing bacteria.

However, comparatively few types of bacteria are pathogenic. Most of them have some useful function. They are the chief agency in decomposition and decay by which they help to restore organic materials into the general circulation of nature's economy.

Bacteria spoil food and rot substances which then become soil fertilizers; they sour milk and ripen cheese; they break down tissues in disease, and aid in digestion. They, therefore, do much that makes life in the higher organisms possible, while at the same time doing many things which cut that life short.

While it was only after microscopes were invented that bacteriology could become a science, still it has always been known that acid solutions and salt solutions keep food from spoiling and that heavy sugar solutions do the same. Thus it was possible to pickle and preserve foods and to make jellies.

Bacteria require heat and moisture for their growth, so that fruit and meats can be dried, and by preventing one of the important factors for bacterial life from being available, such meat can be preserved for great periods.

Drugs and chemicals which prevent the growth of bacteria are known as **antiseptics**. Thus, wine was used as an antiseptic by the ancients which they poured on wounds. We use alcohol to-day instead of wine.

In agriculture there are certain soil-bacteria which produce tiny

galls ( ), commonly known as **tubercles** (Fig. 90), on the roots of clover and other leguminous ( ) plants. These serve a very important purpose in that they derive nitrogen directly from the air and supply it to the clover. This makes it possible for clover to grow in soil very poor in nitrogen, while the overproduction of nitrogen leaves the soil richer than it was before.

The galls themselves are filled with rather large x- and y-shaped bacteria, easily seen under the microscope. These bacteria die, and the nitrogen which they contain is added to the surrounding soil, sometimes directly, and sometimes through the intermediate plant to which it is attached.

CHAPTER XIV.

IMMUNITY

Whether the study of biology be taken up by those who intend practicing medicine, or for general cultural purposes, the fact remains that all of us, at some time in our lives, require the se vices of a medical man. Likewise, all of us who make any pretense whatever at being college men and women feel, and rightfully so, that unless we can intelligently follow at least the ordinary scientific articles appearing in various magazines and journals written for educated men and women, there has been some radical defect in our instruction.

In view of the fact that practically all modern medicine is based upon the theory of immunity, neither the medical man, the medical student, nor the educated man at large, can intelligently discuss or intelligently understand anything that may be told him regarding himself or the method of treatment suggested when disease comes to him, unless the theory of immunity is understood.

The subject of immunity is rather difficult, in fact, probably one of the most difficult that confronts the first and second year student of biology; but his ability to grasp and understand the theory is, in a way, a test of his ability at understanding and applying the knowledge he has gained in biology.

As all coelomates have their bodies arranged as one tube lying within another, if one could draw out any coelomate body lengthwise, the outer part would appear as a tube with very thick walls, while the gastro-intestinal-tract would form an opening through the entire body. In fact the whole body would appear quite similar to an ordinary thickened gas pipe (Fig. 164).

One can readily understand that the opening in the gas pipe is really subject to the same atmosphere and environmental conditions that the outside of the pipe may be. So, too, the intestinal tract with all its diverticula is really outside of the body in so far as the atmospheric surroundings are concerned. In fact, the interior portion of the gastro-intestinal-tract is just as much outside the body (although not quite as much exposed) as is the skin on the outer surface.

Now, the surface on the inner side of the gastro-intestinal-tract, just as the skin, forms a layer that can, under certain conditions, be penetrated by either physical, chemical, or living substances. We know that we can scratch or cut ourselves. This results in a physical injury. We know that poisons are chemicals which can injure tissues whenever such poisons get into the system, and we also know that living organisms such as bacteria (unicellular organisms from the plant world), and protozoa (unicellular organisms from the animal world) can take up a sort of parasitic life within other living forms. Whether a given substance injures chemically, or whether a living organism is to find its way into another and injure it, depends upon whether or not the foreign substance or organism can penetrate through the outer skin surface of the body or through the surface of the gastro-intestinal-tract. It is only when such foreign objects are able to get **within the body proper** (that is, within the space between body surface and intestinal surface) that injury results.

Probably most of such injurious substances are taken in through the mouth and later find their way through the more or less delicate lining of the gastro-intestinal-tract. It is of value to note that the severity of a burn, in the area affected, depends upon the length of time the particular area remains in contact with either fire or acid. This means that a deep or severe burn in a localized area may cause death, while a less severe burn spread over a greater area might not.

Now, if a liquid, which can neutralize or wash away the given substance, could be thrown upon the acid at the time it is spilled, such acid would be washed away immediately and little if any harm would be done. So, too, in the gastro-intestinal-tract, an injurious substance that may find its way therein, may be neutralized or washed away if a sufficient quantity of neutralizing fluid is secreted or passed through the intestinal tract.

Therefore, two things must be kept in mind when discussing a subject of this kind: the **strength or power of the injuring agent,** and **the length of time the injuring agent is in contact with a susceptible surface.** In fact one may add a third factor, for there is a possibility of a foreign substance being taken into the system which may so affect the regenerative abilities of the host, as not only to prevent healing of a wound, but which will actually continue to irritate and injure more than the original injuring agent.

Once the injuring agent has entered the body the question arises as to the method by which it injures the host. It must be remembered that living organisms, whether they be bacteria or protozoa, are in turn subject to the same laws that govern the life of the host itself. Some of the larger parasites, such as tapeworms, really remain within the intestinal tract and use the food of the host before the host himself derives the benefit of what he has eaten. There are also parasitic protozoans, such as the malarial parasite, which, once it has entered the blood stream, actually eats out the center of the blood cells. Then there are those which use some part of either the blood or other tissues of the body for food and in this way injure the host; or again, there are those which use but a very small quantity of the host's food and are consequently not particularly injurious to the host on that account, but the various excreta ejected by these parasites may prove injurious either as a mechanical obstruction of some kind or as a chemical poisoning. And still again, there may be various poisonous substances formed by the parasites themselves which will injure the immediately surrounding tissues of the host only in the location of the parasites; or, the poisons may be soluble in the blood stream and in this way pass throughout the entire body, injuring many regions. And there is still another way by which injury is brought about by parasitical invaders. There are certain bacteria and protozoa which require considerable oxygen for their life processes. The red blood corpuscles have become red by coming in contact with the air in the lungs and absorbing oxygen which they then distribute throughout the body. If the parasite, however, takes this oxygen from the red blood cells, only carbon dioxide and carbon monoxide will remain. Carbon monoxide is "coal gas," a gas which often asphyxiates men working in the coal mines. It therefore follows that one may actually be "gassed" and die of this "gassing," should there be parasites in the body which remove the much needed oxygen from the red blood corpuscles. In such instances where oxygen is withdrawn, death results almost immediately.

Then there may be all manner of **mixed infections,** as they are called. Just as it requires fire in order to cause powder to explode, so there are certain chemical substances as well as living organisms which by themselves do little harm or injury; but, when a second or third substance mixes with them, may prove quite injurious. Conversely, a single substance may be quite injurious, such as either an acid or an alkali, but when the two are mixed they neutralize each other and no active injury is brought about.

Everyone knows that no two people are exactly alike in their ability to resist disease and that one person may tolerate a much greater injury than another without succumbing to it. Most of us have probably read of the ancient king who, being afraid that an enemy might poison him, took small doses of various poisons daily so that in due time he could take great quantities without its having any injurious effect upon him. That is, his **toleration** for this specific poison grew, and his body was able to resist the usual injury caused by such poison. That is, his system became insensible to specific poisons which were thus unable to affect him injuriously because an immunity to these poisons had been set up.

Resistance, tolerance, and **immunity** may be classified in various ways, such as **racial, familial,** and **individual.** As an example of race immunity we have those groups of individuals living in the tropics who do not succumb to the various tropical fevers that affect a stranger almost immediately. The classic example, however, is that of the Jews, who having fought tuberculosis for thousands of years, are now more immune than any other known race of mankind. The negroes and Indians, on the contrary, never having had tuberculosis until the white man brought it to them, succumb quickly.

If certain families seem to be more or less immune we call this a familial immunity, and if only an individual is intensely resistant to a given disease or injury, we speak of it as individual immunity. Immunity is also divided (1) **natural immunity** (under which racial immunity can be classified), and (2) **artificial immunity.** The second of these divisions is again subdivided into **active** and **passive immunity.**

Bacteria either **contain** poisonous substances (endotoxines), as does the Typhoid fever bacillus, or they **produce** poisonous substances (merely called toxins or ectotoxines) as does the Diphtheria bacillus, Tetanus bacillus, etc.

Now, if these toxic substances are distributed within the body, the body tries to protect itself by manufacturing **antitoxins,** which are opposing substances for the purpose of neutralizing the poisons and thus preventing them from injuring the system. If the toxic poisons are not too severe, the antitoxin prevents a disease from forming.

As an example we may cite Typhoid fever. Here the antitoxin is not only manufactured, but actually remains in the body of the patient for some years after the disease has passed away. The great quantity of antitoxin present can, during these years, thus prevent another attack of the disease if the Typhoid bacillus again gets into the body. Such an individual is, therefore, during the time the antitoxin is present in his body, **immune** to new attacks of Typhoid fever. He is immune because his body produced immunizing bodies which protect him. His body is active in producing these immunizing bodies, and such immunity is therefore called an **active immunity.**

An animal which, in a specific disease, also builds up such antibodies or immunizing bodies, may have these antibodies removed from its blood. The liquid part of the blood which contains the antibodies is called an **antibacteriological** or **antitoxic serum.** Such sera are then injected into human beings, and as the person into whom they are injected, then has protective substances which he does not otherwise have, he (without having his own body manufacture the antibodies), becomes immune for a certain length of time to the specific disease for which the **antibodies** were manufactured in the animal's body. Such an immunity is therefore called a **passive immunity.**

It is upon principles evolved from these facts that the various vaccines have been brought forth against Cholera, Typhoid fever, Smallpox, etc., as preventive measures, as well as the therapeutic sera injected **after** the disease is present, as in Meningitis, Diphtheria, Tetanus, etc.

We know that various chemical substances have definite affinities for each other, and to explain the mechanism of immunity it is assumed that every cell in the body has some particular chemical attachment or affinity. Let us say a certain molecule connected with each cell has an affinity for various substances that pass through the body. This molecule is called a **receptor.** We know that normally, as blood passes the different cells of the body, the cells have a **selective action,** that is, they practically reach out and drink in what they need. One of the experiments performed on **Paramoecia** demonstrates what is meant by this chemical selective action. It is there shown that certain chemical substances such as a sugar solution may cause the animal to go in an opposite direction, but if it has once gone into the solution it will not again leave. This selective action which all cells probably possess to some degree, may work on a similar basis; that is, normally, the molecule (the receptor) draws to itself the particular food that it needs as the blood passes. But, just as **Paramoecia** may actually enter the sugar solution or even various injurious solutions, so the molecule or receptor may also sometimes take or select from the passing blood poisonous or toxic substances and unite them with itself. This, of course, injures the cell to which the receptor is attached.

We know from ordinary observation that whenever we injure ourselves sufficiently, a **scar** forms. Then, too, it will be noticed that the scar is almost always slightly elevated. This means that **more scar tissue has actually formed than there was skin before.** From microscopic studies we find that whenever those particular cells known as **fibroblasts** (which form a goodly portion of the connective tissue element of the body) are injured, they grow much more rapidly and profusely than they did before such injury took place; in other words, if the fibroblasts are injured, more connective tissue will grow in the region of injury than grew originally. Once an injury takes place and regeneration or regrowth begins, there is usually an excess of such regeneration or of such growth.

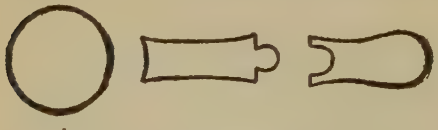

Fig. 91. Diagram Illustrating the Factors Concerned in Immunity.

cl., the cell to be dissolved; *c.*, the complement or solvent by which it is dissolved; *a.*, the amboceptor or intermediate body by which the two can be brought together.

With this in mind it is easy to understand that when a molecule or receptor has anchored to itself a poison (Fig. 91) which injures the cell to which the receptor is attached, the cell may grow several receptors where it had only one before. Such excessive production of receptors causes a portion of the receptors to be thrown off from the cell. These separated receptors then find their way into the blood-stream. The receptors in the blood-stream are able to anchor poisons to themselves just as when attached to cells. This means that there are great quantities of these receptors taking up the poison that would otherwise injure the various cells with which the poisons might come in contact. The receptors thus prevent injury to cells which normally would be open to attack.

Certain conditions, however, must be fulfilled before the receptors can unite to themselves the poisonous substance, and the condition necessary in this instance is that a certain ferment-like substance called a **complement** (or **alexin**) be present. These are protectors against infection.

Complements can be demonstrated to exist in the laboratory. When blood serum is placed in a test tube, the receptors do not unite with the toxin if a very small amount of heat is applied to the serum proper. Heat kills or paralyzes whatever it is which makes the union possible. If, however, we add but a very small amount of unheated serum, the union takes place almost immediately. Whatever it is that has been destroyed by the heating and which permits or causes the receptor to unite with the poisonous substance is called the **complement.**

It is quite possible that certain cells of the body, or even all the cells of some animals, may have no receptors at all for certain poisons, and therefore, such cells and animals would have a natural immunity toward those poisons. It is because the thrown-off receptor needs the complement before it can anchor the poison that they have been called **amboceptors.**

The foreign body or substance is called the **antigen,** while the amboceptor produced by the action of injurious antigens is known as the **antibody.**

It is of great importance to know that the molecule which is the amboceptor is decidedly **specific.** That is, an amboceptor will react only to one specific foreign substance, so that antibodies formed in diphtheria, for example, will not be the same as those formed in tetanus, nor will they be able to assist in anchoring poisons produced in tetanus.

Quite naturally, the rate and ability of metabolism in a cell will determine how rapidly receptors are formed, and consequently will determine how rapidly immunity can be brought about. This means, in turn, that if the poisons can act more rapidly than the cells, the cells as well as the possessor of those cells will succumb.

Phagocytes (white blood cells which devour foreign substances) are also subject to this same rate and ability of metabolism. Some phagocytes may devour a foreign body before the latter has time to bring about an injury.

Some phagocytes may have no chemical substance within them which can dissolve the invader, and so the invader may continue to live even though engulfed by a phagocyte, or, the invader may even kill the phagocyte.

Then it must be remembered that in all parasitic organisms the same conditions largely apply which apply in the host, so that just as the host may strengthen his resistance so the parasite may strengthen its virulence so as to overcome the increasing resistance of the host. For example, capsules form about the bodies of the anthrax bacillus and the pneumococcus, which makes them more resistant to any injurious substances of the host. And these capsules only form in the body of a host where some kind of immunity is possible. In cultures in the laboratory, where no immunity is brought into play, capsules do not form on the groups mentioned.

The encapsulated forms are not subject to phagocytic action, and some even continue to produce more and more powerful poisons to injure the unlucky phagocyte which may devour it.

It is assumed that inflammations and fevers probably cause an increased production of phagocytes and chemical neutralizations to protect the body in injury and disease.

The amboceptors anchor soluble poisons only when the complement is present.

Similarly, phagocytes will not engulf bacteria unless the bacteria have first been prepared for such engulfing by a substance in the normal blood serum similar to the complement called **opsonins.** If an animal has already been immunized by repeated introduction of bacteria, still more resistant bodies called **bacteriotropins** appear. These bacteriotropins (which are only a sort of outstanding opsonin in immune sera) act as opsonins and prepare the bacteria for the phagocytes. Opsonins, bacteriotropins, and in fact all substances which prepare foreign substances for the phagocytes are called **cytotropins.**

When foreign bodies of any kind dissolve body substances they are said to be cytolytic (cytes-cell+lysis-dissolving) if they dissolve the cytoplasm; haemolytic, if they dissolve the red substance (haema=blood) in the blood cell; hepatolytic (hepar=liver) if they dissolve liver cells, etc., etc. Such lysins are usually antibodies.

If a reaction can be produced which will cause bacteria or cells to clump together, such clumping is called **agglutination,** while the substances in immune sera which cause agglutination are called **agglutinins.** This is commonly called the Widal reaction. Agglutination is so specific that the serum of an individual suffering from typhoid fever, or even the serum of one who has had the disease, will cause the clumping of typhoid bacilli when a few drops of it are placed in a culture of the bacilli.

If any foreign protein substance is injected into any of the higher animals, new substances similar to antibodies are formed, which are also specific in acting on the same protein substances by causing a cloudy precipitate, and sometimes by changing the protein by breaking it up into simpler substances, some of which are poisonous. This fact makes it possible to tell whether blood stains are those of a human being or not. For example, the clear serum of a rabbit can be treated with human blood serum and if even a portion of the dissolved human blood stain is then added, a cloudy precipitate forms, although this precipitate will not form when blood from a lower animal is added. Similarly if the rabbit's blood be first treated with the blood of a lower animal, human blood will not cause the precipitate.

A strange phenomenon has also come forth in recent years known as an **anaphylactic** shock. This is probably connected in some way with the precipitation reaction. It means that an animal already immunized to a protein may die when additional protein of the same kind is injected. This condition in an animal is known as **anaphylaxis** ( ). In other words, we may say anaphylaxis is an oversensitiveness of the organism toward bacterial toxins and foreign sera. The reason for anaphylaxis is not yet satisfactorily explained.

The principle of anaphylaxis is used to diagnose certain diseases. The tuberculin reaction is nothing more nor less than the injection of the proteins of the tubercle bacillus into the skin, which (because the dose is very small) does not overwhelm the entire nervous system, but produces only a fall in temperature and a slight fever, if the disease is present.

An **antitoxin** is, as already stated, the soluble substance produced which neutralizes quantitatively fresh injections of the same poison. The commercial diphtheric antitoxin is merely the serum of a horse which has had repeated doses of diphtheria toxin injected until it has been brought into a state of active antitoxic immunity. Like all immunizing agents antitoxins are all specific for some single toxin.

In this connection it is interesting to note that while sheep are very susceptible to the toxin formed by the tubercle bacilli, they are not susceptible to the injection of the dead bacilli themselves. Guinea pigs are quite susceptible to the bacilli but not to the toxin. The proteins of one's own body injected into ourselves are poisonous.

The various ways in which immunity is produced by injection of foreign substances may be summarized as follows:

(1) The virulent parasites are administered in small doses so as to give the individual the disease in a mild form (active immunity).

(2) Weakened parasites may be injected in larger doses and produce the same result.

(3.) Dead bacteria may be given in place of living, so as to produce a feebler but similar result.

(4) The poisons may be isolated from the parasites, and gradually increasing doses are injected, thus increasing the normal neutralizing ability of an individual.

(5) Serum from an animal, immunized by one of the above processes, may be placed directly into another individual and thus permit him to become immune without going through any form of the disease himself (passive immunity).

CHAPTER XV.

THE PLANT-WORLD

SIMPLE PLANTS

Everyone is already familiar with some of the higher groups of plants known as "flowering plants," but everyone is not familiar with the fact that flowering plants are few in number, indeed, when compared with the thousands of different kinds of minute plants that cannot even be seen with the naked eye, and which do not bear flowers.

Prominent among these latter are such single celled plants as Pleurococcus, the yeasts, and bacteria already studied. But there are others also, which, though commonly seen, must remain unknown unless observed under the microscope.

To be able to discuss the plant-world intelligently one must know certain terms commonly used, just as it was necessary to know the various names of the many parts of the frog before the animal-world could be intelligently discussed.

The following outline and drawing (Fig. 92) will give such a knowledge of terms:

- Plant Body
  - Root (with or without branches)
  - Shoot
    - Stem (with or without branches)
    - Blade
      - Apex
      - Margin
      - Base of the Blade
      - Veins
    - Leaves
      - Petiole (the leaf stalk)
      - Leaf-base
      - Stipules. (Small leaf-like structures at the base of the petiole).

There are as many and varying classifications of plants as there are of animals, but, **four great groupings** hold their own because these groupings are simple and easily understood.

They are as follows:

Thallophytes ( ). Plants possessing a simple plant body.

Algae (Chlorophyl-bearing thallophytes).

Fungi (Thallophytes without chlorophyl).

Bryophytes or **Moss Plants** ( ).

Pteridophytes and their allies ( ). The Ferns and their allies.

Spermatophytes or Seed Plants ( ).

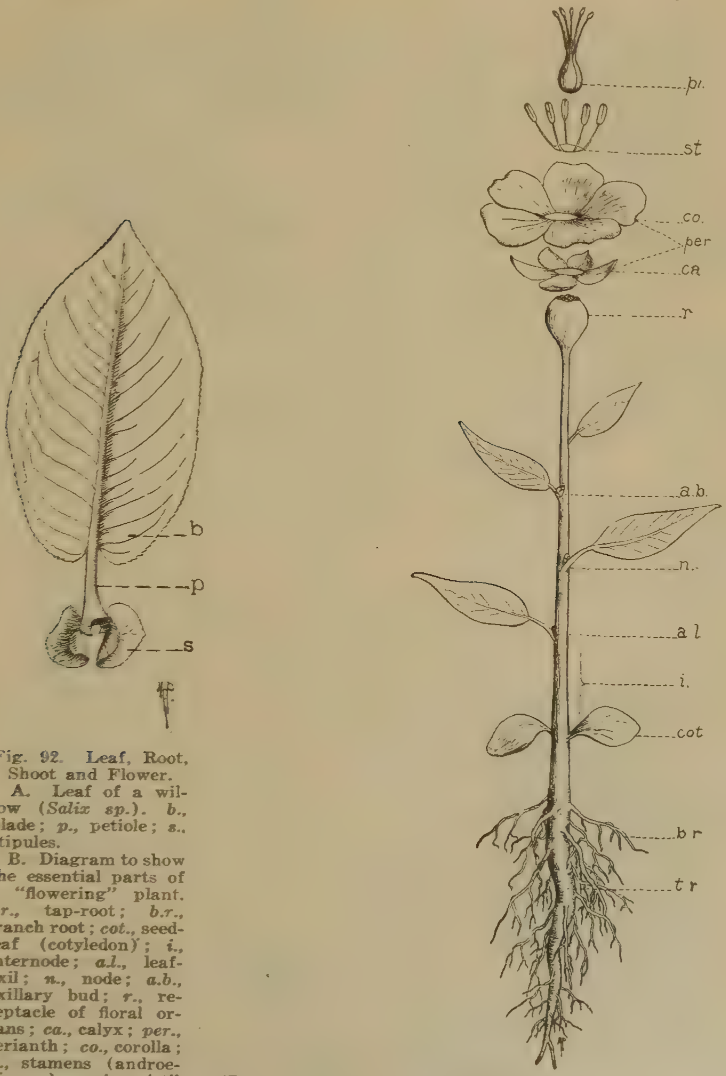

Fig. 92. Leaf, Root, Shoot and Flower.
A. Leaf of a willow (*Salix sp.*). *b.*, blade; *p.*, petiole; *s.*, stipules.
B. Diagram to show the essential parts of a "flowering" plant. *t.r.*, tap-root; *b.r.*, branch root; *cot.*, seed-leaf (cotyledon); *i.*, internode; *a.l.*, leaf-axil; *n.*, node; *a.b.*, axillary bud; *r.*, receptacle of floral organs; *ca.*, calyx; *per.*, perianth; *co.*, corolla; *st.*, stamens (androecium); *pi.*, pistil (gynoecium).

(From C. Stuart Gager's "Fundamentals of Botany," by permission of P. Blakiston's Sons & Co., Publishers.)

THALLOPHYTES

Thallophytes—These plants have a mere **plant body,** there being no true stem, roots, or leaves, though there may be parts that resemble stems, roots and leaves. They may be very fragile as are some of the thread-like green **Spirogyra** (Fig. 93), (also called **pond-scum** and **frog-spit),** commonly found in fresh-water creeks and ponds, or tough **sea-weeds** like the **brown kelp** many feet in length. The cells usually grow end to end.

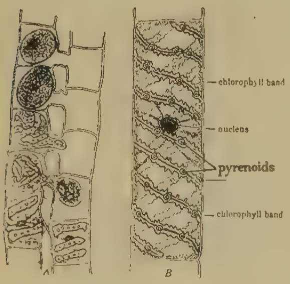

Fig. 93.
The band-like chloroplasts extend in a spiral from one end of the cell to the other. In them are imbedded nodule-like bodies (*pyrenoids*), and near the center of the cell the nucleus is swung by radiating strands of cytoplasm. (After Strasburger.)

As has been seen by this time, when living organisms are discussed, there are no hard and fast rules by which one may classify anything. There are some Thallophytes which really have stem-like and leaf-like structures, but the classification originally based on structures, must now be thought of more from a **functional** or **life-cycle** point of view. All thallophytes are alike in having a more or less simple life-cycle, so this must serve us as a basis.

The various algae (Fig. 94), are named after some distinctive characteristic; thus those which are **green** are called **Chlorophyceae** ( ), those which are **red, Rhodophyceae** ( ), those which are slimy **Myxophyceae** ( ), etc.

Spirogyra ( ) is in turn a representative of the **chlorophyceae.** The cells are elongated and attached end to end. There are spirally arranged bands (chromatophores or chloroplasts) which contain chlorophyl. The number of these bands and the method of coiling depend upon the species to which each belongs. The cytoplasm is rather thin and lies next to the cell-wall, while fine threads of it extend to the nucleus. The special centers in the chloroplasts where starch is stored are called **pyrenoids** ( ). Nearly 98 per cent of the cell is water, yet the 2 per cent remaining can perform every one of the four vital processes. The bubbles often seen are filled with oxygen which is a waste product of photosynthesis.

Reproduction takes place in two ways, either by the individual cell dividing at right angles to the length of the cell, or after two individuals have conjugated. The latter is seen when two plants lying close together send out projections (Fig. 95) which unite, forming bridges through which the cytoplasm of one plant mixes with another. In fact these two cells may unite so thoroughly that they become one,

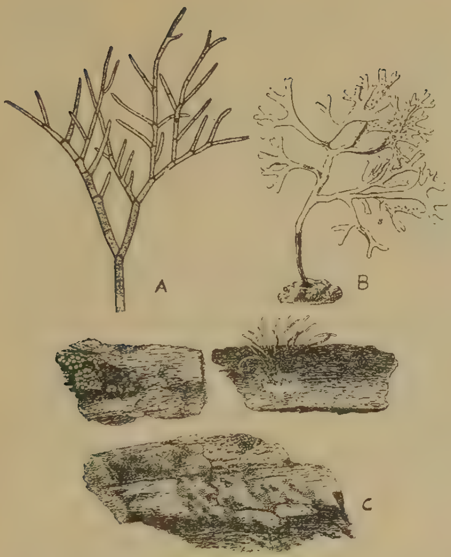

Fig. 94. Chlorophycae, Rhodophycae, and Myxophycae.

A. *Cladophora*, a branching green alga, a very small part of the plant being shown. The branches arise at the upper ends of cells, and the cells are cœnocytic.

B. A red alga (*Gigartina*), showing branching habit, and "fruit bodies."

C. Three common slime moulds (Myxomycetes) on decaying wood: To the left above, groups of the sessile sporangia of *Trichia;* to the right above, a group of the stalked sporangia of *Stemonitis*, with remnant of old plasmodium at base; below, groups of sporangia of *Hemiarcyria*, with a plasmodium mass at upper left hand. (A, after Caldwell; B, after Schenck; C, after Goldberger.)

becoming smaller as a thickened wall is secreted about it. When this latter event takes place the organism is said to be in a **spore state,** and because the spore has been formed by the fusion of two cells it is often called a **zygospore** (-). Conjugation is thus a preparatory process to permit a mixing of the parent chromatin before actual reproduction takes place.

It has already been explained that a sexual germ-cell is known as a **gamete.** The zygospore is therefore now one cell, the product of the fusion of two **gametes.** There is here then the beginning of sex-life in the plant-world; this is why the two conjugating and fusing parent cells are known as gametes.*

The spore cannot escape from the parent cell, however, until such parent-cell decays.

Artificial Fertilization. — "More than a hundred years

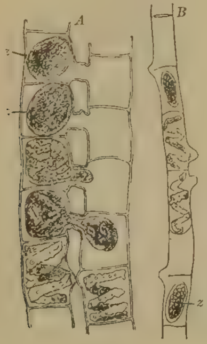

Fig. 95.

The Union of the Gametes in *Spirogyra*.

A, two filaments of *Spirogyra quinina*, side by side, showing stages in the union of the cells (gametes) to form the zygospores; *B*, another species (*S. longata*), in which the cell unions occur between adjacent gametes in the same filament. (After Schenck.)

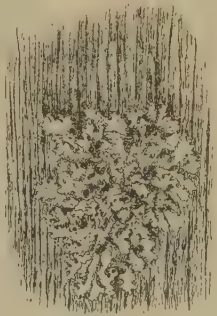

Fig. 96. A Common Foliose Lichen (*Parmelia*) Growing Upon a Board, and Showing Apothecia. (After Goldberger.)

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*This is the first sign of two sexes we shall see in the laboratory, although the very first sexual differentiation in plants probably lies in the *Volvacales* (Fig. 97).

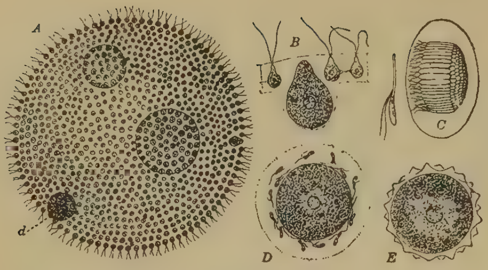

Fig. 97.
Volvox Globator, a Colonial Form of the *Volvocaceæ*.

(See Fig. 49, where this same form is considered an animal.)

A, mature colony, with four daughter colonies developing in its interior; *B*, section of the edge of the colony, showing three vegetative cells and a developing egg; *C*, a packet of sperms within the parent cell and a single sperm very much magnified at the side; *D*, an egg surrounded by a swarm of sperms; *E*, an oöspore with heavy protective wall. (From Bergen & Davis' "Principles of Botany," by permission of Ginn & Co., Publishers.)

ago Spallanzani succeeded in artificially fertilizing eggs of various animals; but more recently several workers have succeeded in causing the egg to begin growing by chemical means. These men saw that the formation of the fertilization-membrane is purely physical, so biologists began to reason that it ought to be possible to induce it artificially. The experiment was first successfully made by a zoologist, Loeb, with the eggs of sea-urchins and other marine animals. In 1913 it was successfully accomplished by Overton with the eggs of **Fucus**. The eggs were dipped for about a minute, or a minute and a half to two minutes, in a mixture of 50 cc. of sea-water plus 3 cc. of a very weak solution of acetic, butyric, or other fatty acid, and then transferred to normal sea-water. This treatment caused the formation of the fertilization-membrane, quite as in natural fertilization by the sperm. If, after the formation of the membrane, the eggs are placed for 30 minutes in **hypertonic** sea-water (50 cc. of normal sea-water plus 8 to 10 cc. of a weak solution of sodium chloride (common salt), or potassium chloride), and then back into normal sea-water, the eggs begin to divide and continue to de-

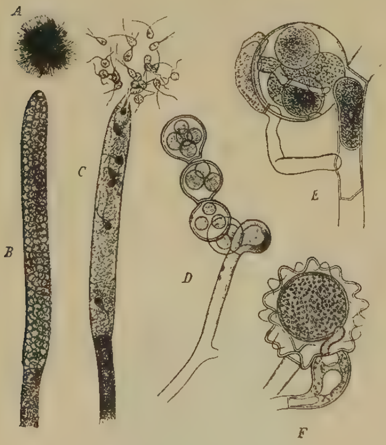

Fig. 99. *Phycomycetes.*

These are the alga-like fungi without septa in the mycelium, except in the sporing branches, where they occur to cut off the spore-bearing cells. The septa also occur in old filaments. The mycelium is therefore continuous.

Common water mold (*Saprolegnia*): *A*, a fly from which mycelial filaments of the parasite are growing; *B*, tip of branch organized as a sporangium; *C*, sporangium discharging biciliate zoöspores; *F*, oögonium with antheridium in contact, the tube having penetrated to the egg; *D* and *E*, oögonia with several eggs. (*A-C* after Thuret; *D-F* after De Barry.)

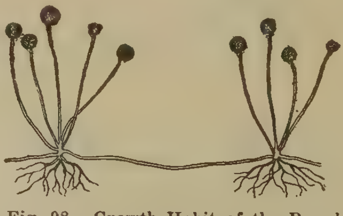

Fig. 98. Growth Habit of the Bread Mold (*Rhizopus Nigricans*).

Sketch showing two groups of erect hyphæ bearing sporangia, with root-like clusters of filaments at their bases.

velop into young plants. The question as to the chromosome number in the cells of plants formed by artificial fertilization is of very great interest, but has not yet been investigated."

It must be remembered that the egg was already there. Artificial fertilization merely hastened a normal action. This does not throw any light on the origin of life, as is popularly supposed.

VAUCHERIA

This is the common **"green felt"** (Fig. 86), usually found on soil, though it is often found in water. The thread-like filaments are coarser and longer than spirogyra and they also branch. Vaucheria are **tube algae.**

There is an interesting difference here from the spirogyra in that there are **no transverse cell-walls** throughout the entire filament, but there are many nuclei scattered about. Such a form is called a **coenocyte** ( ) or **syncytium** (I. E., Fig. 86).

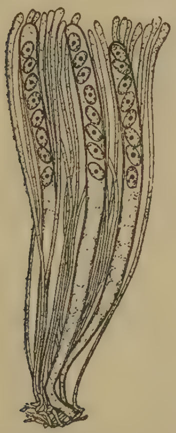

Fig. 100. *Ascomycetes* (Sac-like Fungi).

The figure shows the characteristic grouping of asci. The layer in which the asci appear is called a hymenium. In these the mycelium has dividing septae and the spores are contained in asci. (After Chamberlain.)

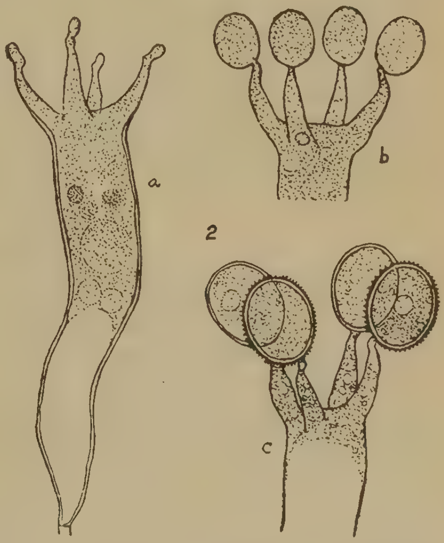

Fig. 101. *Basidiomycetes.*

Typical basidium with sterigmata (distal short stalks), showing spores in different stages of development. (After De Bary.)

In basidiomycetes the spores develop on little club-shaped hyphae. Smuts, rusts and mushrooms belong in this group.

Reproduction takes place **both sexually and asexually** (Fig. 86). In the latter case the old end of the filament dies, setting free the branches which become separate plants, or a **cross wall** forms in one of the branches. A thickening occurs beyond this cross wall and this thickening is known as a **zoöspore.** The zoöspore breaks away from the parent plant, swimming about for a time and then becomes a new plant.

It is made up of many cells but forms only one plant.

Sexual reproduction occurs when one or more large oval protrusions form on branches which have grown out apparently for this purpose. At the very end of this branch is the **terminal** cell in which many small cells are formed. These small cells escape into the water. Each one possesses long cilia by means of which it swims about. A single one of these ciliated forms enters the oval mass. The little ciliated form is known as the **male gamete**, and the large oval protrusion as the **female gamete.** The **organ which produces a gamete** is called a **gonad*** ( ), The oval body is consequently known as an **oögonium** ( ) or **egg-gonad.** Two gametes, uniting as have the two just mentioned, form a single cell known as an **oöspore.** This oöspore, after a short period of rest, forms a new plant. It will be noted that in Vaucheria the gametes are of **unequal size.** In Spirogyra they were of **equal** size. In fact, **whenever gametes are formed,** it is **the smaller** and **more active** one, regardless of whether there are any other distinguishing features or characteristics, which is called the **male gamete** or **sperm,** while the larger and more passive one is known as the **female gamete** or egg.

The union of sperm and egg **is** called the process of **fertilization.**

The **male gonad** is called the **antheridium** ( ) and the **female gonad** is known as an **oögonium.**

Some algae live with various fungi. These **symbiotic** ( ) plants are the **lichens** ( ). (Fig. 96.)

THE FUNGI

The **Algae-like,** or **tube fungi,** make up the **Phycomycetes,** while the higher fungi such as mushrooms, toad-stools, puff-balls, rusts, and smuts, are known as **Carpomycetes.**

The fungi, no matter how differently they may appear or in what out-of-the-ordinary place they may grow, are alike in two great characteristics. 1. **They possess no chlorophyl,** and 2. **They reproduce by spores.**

They live either upon decaying matter, in which case they are called **saprophytes,** or at the expense of another organism when they are called **parasites.**

Bread Mold is easily obtainable, but that from fruits or from dead flies serves just as well for study. (Fig. 98.) There is a tangled mass of **thread-like structure** which is the working body of the plant. This tangled mass is known as **mycelium** ( ), while the individual threads are known as **hyphae** ( ). If the hyphae send out threads in turn these are called **rhizoids** ( ), and it is these little root-hairs which penetrate the substance on which the mold forms and through which it absorbs what is needed. It is supposed that **enzymes** are produced **in the hyphae** which can make the bread or fruit utilizable to the plant.

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*Botanists do not look with favor on the term "gonad" in plants, but it has seemed advisable to use this term here, for, in zoology the student must use it constantly.

Reproduction takes place by a number of **upright stalks** called **sporangiophores** ( ), growing from the mycelium. There is formed a **spore-case** or **sporangium** at the very tip of the stalk. In this the spores are formed and when the spore-case bursts the dust-like particles which are really spores are scattered about by air currents.

There may be **sexual reproduction** in the molds quite similar to that in Spirogyra. Two hphae unite by their free ends and a wall forms, thus producing **two end cells** which eventually become a **single spore with a very dark heavy wall.** Here again, **the gametes being similar,** the resulting body is a **zygospore.** The sexual process does not occur very often.

It is to be remembered that molds are plants. But growing as they do in the dark, they have no chlorophyl and do not make their own food, but feed on food already prepared; not on ordinary plant or animal food as does man, for example, but on decaying matter or on food that has already been digested by the host, either before or after assimilation.

The so-called water-mold is both parasitic and saprophytic as it can thrive either on dead or living fish. This means that molds are a **degenerate form of green plants** which have **acquired a habit** of making some other organism do their work for them, rather than build their own food by photosynthesis as plants usually do.

PATHOGENIC FUNGI

Some of the difficulties of classification may be observed here by noting that botanists classify **fungi** or **mycetes** ( ) as follows:

1. **Phycomycetes**: algae-like fungi. (Fig. 99.)

2. **Ascomycetes**: sac-fungi (asci); Asexual spores formed in sacs. (Fig. 100.)

3. **Basidiomycetes**: spores, born on little club-shaped hyphae, or basidia. (Fig. 101.) (Includes smuts, rusts, and mushrooms.) The pathogenic fungi bear many names and cannot be accurately placed, because pathologists use other than the regular botanical terms and meanings, as shown by the table below.

Most infectious diseases due to **vegetable parasites** are caused by **bacteria,** but a few owe their origin to micro-organisms of a higher type, namely, to the **yeasts** and **molds.** Two of the infectious processes caused by yeasts, although comparatively rare, deserve brief consideration. Both the organisms and the **lesions** they produce, microscopically and in gross, resemble each other more or less closely. For this reason they were for a long time confused with each other, but the differential characteristics are now fairly generally recognized.

The relation of the **yeasts** or **blastomycetes** to the bacteria and the molds is shown in the following diagram:

Pathogenic Protophytes.
(These are all Chlorophyl-less plants.)

Schizomycetes ( )
(bacteria)

Hyphomycetes ( )
(molds)

Blastomycetes ( )
Saccharomycetes ( )
or
Ascomycetes ( )
(yeasts.)

Oidia ( )
(transition form)
Oidium.

Blastomyces.

A living organism may be injured either **mechanically** or **chemically.**

Mechanical or physical injury may be the result of **violence, pressure, heat** (burning), **cold** (freezing), **light rays,** and **electricity.**

Chemical injury results from poisons (toxins), whether by auto-intoxication, or toxins produced by animal or vegetable parasites.

It is readily understood that a parasite may cause either mechanical or chemical injury to its host: the former by propagating so rapidly that it causes a physical obstruction, as is the case with the Tubercular bacillus; and the latter by a definite poison that the foreign organism produces. The poison, or the mere mechanical effect, may in turn cause some out-of-the-ordinary conditions, as for example when it furnishes a stimulus to overgrowth on some part of the host, as **galls** on trees (a growth caused by the stimulus of **aphids**), or tumors in human beings. These latter are merely overgrown healthy cells.

These overgrown healthy cells may press against neighboring blood vessels, obstructing the blood-flow and thus causing the death of the tissue which fails to receive its required amount of blood.

It may be stated in this connection that there are some hosts which are not affected at all, or but little, by the poisons parasites produce, although the parasite itself does many such hosts a great deal of damage.

The subject of toxins is among those of which no great knowledge has yet been obtained. They are of great interest and importance as can readily be judged from what has been said.

Probably, if **toxins** and **enzymes** are thought of here in relation to each other, it will lead to a clearer understanding of each. Both can be studied only by the **effects they produce,** the one injurious, the other beneficial.

One may also think of several other possibilities on the part of the invading organism. For example, it may live entirely at the expense of its host, in which case it is a **parasite**; it may live on decayed matter and do little if any injury, and thus be a **saprocyte,** or it may actively engage in killing and devouring parasitic invaders and thus be of great value to its host, when it is known as a **phagocyte.**

True yeasts grow **by budding** (Fig. 87); they **rarely form mycelia**; under unfavorable conditions of growth they may form **endospores.**

Oidia grow by budding and as **mycelia with spore formation.** (Fig. 102.)

Hyphomycetes (Fig. 98) grow as mycelia **with spore formation of asexual or sexual origin.**

All authorities seem agreed that there is no sharp line of demarcation between the blastomycetes and the hyphomycetes, and most of them place the oidia as a transition form.

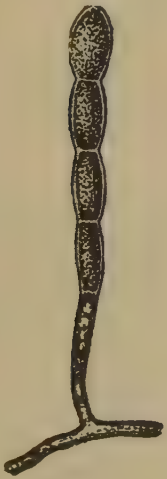

Fig. 102.

Oidium, showing spores being cut off from the tip of the branch. Such spores are called *conidiospores.*

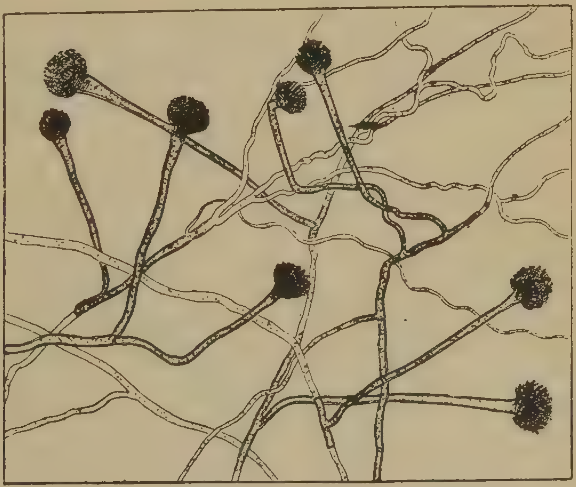

Fig. 103. *Aspergillus Fumigatus.* (After Brumpt.)

Blastomycosis (also called Saccharomycosis), is the term applied to the lesions produced by a blastomyces. A variety of organisms have been cultivated from the lesions, and different names have been assigned to them. "It is not known if these are distinct entities. Most study of this type of organism has been about Chicago.

"There is an infection in the skin, usually remaining localized there, but it may invade the circulation and cause lesions in other parts of the body.

"The blastomyces occur in human tissues only in the **blastomycetoid** form, that is, as small round bodies with granular protoplasm, and with thick hyaline capsules. They multiply by budding only. In cultures they may develop mycelia or grow by budding, or in both ways. They may be numerous in the lesions which they produce, or few and hard to find."

They produce a fairly strong toxin.

Aspergillus fumigatus (Fig. 103) is an example of the **pathogenic** ascomycetes. It is a fungus widely distributed, usually as a harmless parasite, having been found in the auditary canal, nose, and throat.

In birds, in cattle, more rarely in dogs, Aspergillus may cause lesions of the lungs, resembling tuberculosis, and there have been of late years a good many cases reported in man, particularly pigeon keepers and hair sorters. "In the majority of cases the infection is secondary to some long-standing affection of the lungs," though it also causes a primary lesion resembling broncho-pneumonia, usually quite serious. The patient coughs up a grayish brown mass the size of a bean made up entirely of mycelium and spores.

Oidiomycosis (granuloma coccidioides) is the term applied to the lesions produced by an Oidium variously named in the past immities, coccydioides, etc., but not yet definitely classified by the botanists. Infection with this organism is rare and is confined almost exclusively to California. The disease is practically fatal.

The oidium occurs in human lesions in the form of spherical bodies which may reach a size of thirty microns. They consist of an irregularly staining mass of protoplasm enclosed within a double contoured capsule which is occasionally covered with prickles, or even long spines. The organisms multiply in tissues only by endosporulation, never budding. The spores may number as high as a hundred or more. They are liberated by the bursting of the capsule. The number of parasites in the lesions varies. They may be many or few and hard to find. In cultures the oidium grows as long septate branching hyphae. In time, spores develop in the ends of the hyphae and are infectious if inoculated in animals; the hyphae themselves are not.

The lesions produced by Oidium often bear a close resemblance to those caused by the tubercle bacillus, and have probably been mistaken for them more than once on histologic examination. If the organisms are few in number, a cheesy region may be formed, and if numerous, even abscesses and ulcers.

Blood and lymph streams seem to carry the organism so that it is widely distributed. It is as likely to be found primarily within, as on the skin of the body.

Like the tubercle bacillus, Oidium involves the same organs; lungs, lymph-nodes, adrenal glands, meninges, seminal vesicles, etc.

The skin lesions are chronic and consist of nodules, abscesses, and ulcerations.

DISEASES CAUSED BY FUNGI OF MORE OR LESS UNCERTAIN POSITION

Actinomycosis or lumpy jaw.

SPOROTRICHOSES

The **Sporotrichoses.**

(a) **Subcutaneous.** Small solid nodules, becoming abscesses, ulcerating the skin.

(b) **Cutaneous.** Principally in arms, hands and legs, though it may occur on other parts of body. Ulcers form in groups of two or three.

(c) **Localized,** hard and eroded on surface.

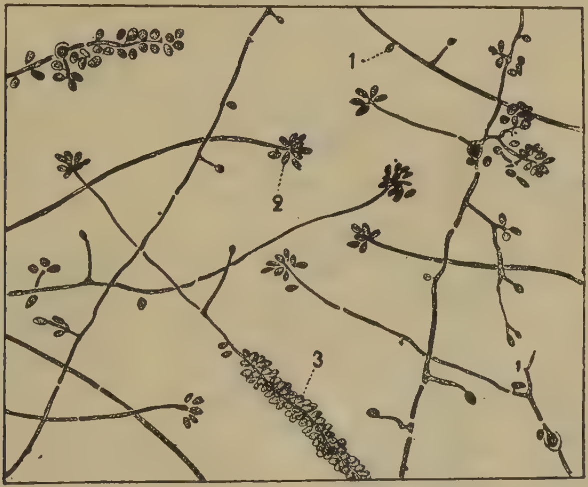

Fig. 104. *Sporotrichum Beurmanni.* (After Brumpt.) 1, Single lateral conidiospore; 2, terminal conidiospores; 3, collection of laterial conidiospores.

The parasite (Fig. 104) is "introduced by accidental inoculation, and possibly through grains and fruit." Acts like bacteria, producing toxins, toward which toxins there are active reactions of the body-fluids. It is a short rod 3 to 5 microns long and 2 to 3 microns in breadth. In cultures it grows in filaments of about 2 microns in diameter and forms characteristic ovoid spores.

"The points of differentiation between the forms are due largely to variation in the modes of sporulation."

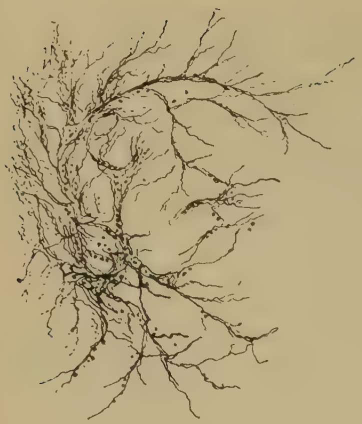

Fig. 105. *Actinomyces Bovis.*

(After Rivas.)

Parasite producing actinomycosis (lumpy jaw). Actinomyces bovis, also called *nocardia actinomyces, nocardia bovis, streptothrix actinomyces, streptothrix israeli, oöspora bovis, cladothrix actinomycoses,* and *bacterium actinocladothrix.*

Nocardiosis. "On the one hand the parasites (Fig. 105) resemble bacteria, on the other hand the hyphomycetes or molds, in forming branching, thread-like filaments, and the production of fine conidia. They represent a **transition** between the bacteria and the lower fungi." Only a dozen cases have been reported. Very like tuberculosis or multiple abscesses, three cases have appeared as abscesses of the brain.

Mycetoma or Madura disease. Largely in India, though it does occur in other parts of the world. There is great swelling of the foot, generally on the sole, nodular growths and multiple abscesses. Black, brownish, or yellow granules are formed, one micron in diameter.

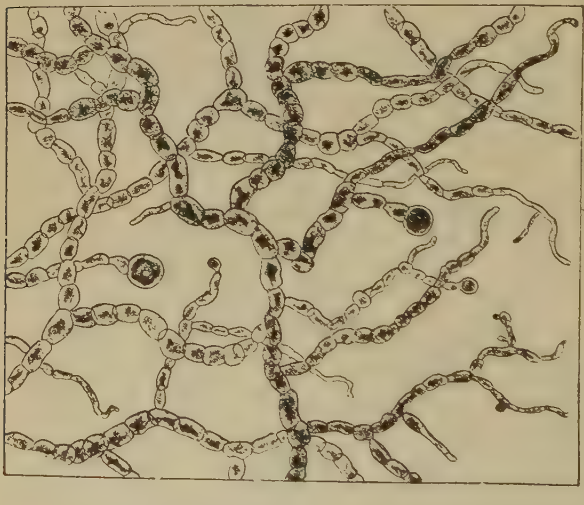

Fig. 106. *Madurella Mycetoma.* (After Brumpt.)

A variety of Streptothrix (Fig. 106) has been found in the pale colored granules, closely resembling Actinomyces. "It is held by most observers that this **Streptothrix madurae** and **Actinomyces** are distinct species." "From the black variety of granules a hypomycete has been grown, an organism closely allied to Aspergillus."

In medicine, all diseases caused by any non-bacterial fungi are sometimes called **Mycosis.**

It is worthy of note that medical men, being most interested in disease, take **similar appearing** lesions as their basis for classifying organisms, while biologists classify organisms according to structure and development, often with little reference to what disease such organisms may cause.

CHAPTER XVI.

THE PLANT WORLD CONTINUED

THE THREE HIGHER GROUPINGS

BRYOPHYTES

Bryophytes are usually said to possess **archegonia** ( ) or **primitive egg gonads** composed **of many cells** as contradistinguished from the **thallophytes** which, **when they possess gonads at all,** are practically always **composed of single cells.**

Bryophytes are moss-plants and liver worts, and their life-cycle consists of two stages, the sexual and the sexless. When these stages follow each other it is called an **"alternation of generations."** The **sexual plant** or **gametophyte** forms **eggs** and **sperm** which unite, while the **asexual plant** or **sporophyte** is the plant which grows from the fertilized egg of the sexual plant. This non-sexual plant forms asexual spores which in turn grow into gametophytes.

Bryophytes may be quite simple resembling the thallophytes, or form a leafy stem as in the mosses.

There are some 12,000 different species of mosses or **Musci,** as they are technically known. These are divided into three distinct orders:

1. **Sphagnales** ( ). The peat-mosses. (Fig. 107.)

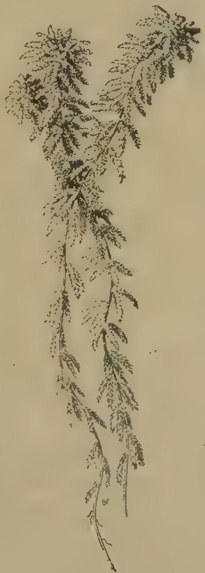

Fig. 107.
The Peat Moss,
Sphagnum.

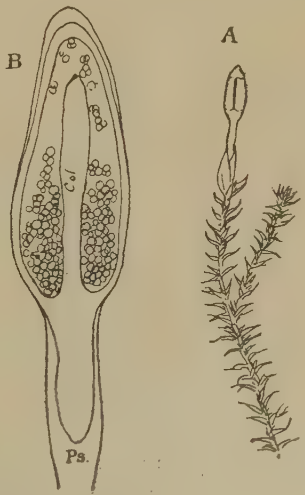

Fig. 108. *Andreaea Petrophila.*
A, plant with mature sporophyte. B, longitudinal section of sporophyte. Ps, pseudopodium; col, columella. (From D. H. Campbell's "A University Text-Book of Botany," by permission of The Macmillan Co., Publishers.)

2. **Andreaeales** ( ). The black-mosses. (Fig. 108.)

3. **Bryales** ( ). The true mosses. (Fig. 109.)

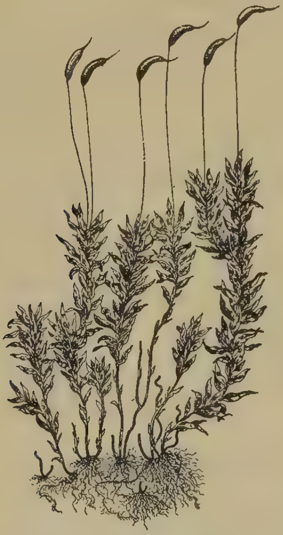

Fig. 109. A Common Moss (*Catharinea Undulata*).
Showing the branching leafy moss plants (gametophytes) attached to the root-like mass of protonemal filaments and bearing sporophytes. (After Sachs.)

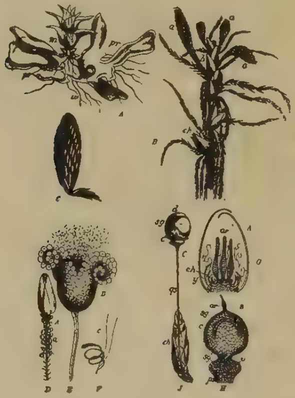

Fig. 110. *Sphagnum Acutifolium*, Ehrb.
A., prothallus (*pr.*) with a young leafy branch just developing from it; *B.*, portion of a leafy plant; *a.*, male cones; *ch.*, female branches; *C.*, male branch or cone, enlarged with a portion of the vegetative branch adhering to its base; *D.*, the same, with a portion of the leaves removed so as to disclose the antheridia; *E.*, antheridium discharging spores; *F.*, a single sperm; *G.*, longitudinal section of a female branch, showing the archegonia (*ar.*); *H.*, longitudinal section through a sporongonium, with dome of sporogeneous tissue; *ar.*, old neck of the archegonium; *J.*, *Sphagnum squarrosum* Pers.; *d.*, operculum; *c.*, remains of calyptra; *qs.*, mature pseudopodium; *ch.*, perichætium. (After Schimper.)

The **Sphagnales** are the **most primitive**, and the **Bryales** the most **highly developed.**

Sphagnum (Fig. 107) is a peat-moss, growing, as its name implies, in swamps and along the margin of lakes. The peat-bogs of northern regions are made up of thick clumps of this plant. Peat-mosses are usually light green in color bordering on white, and sometimes have a slight tinge of red and yellow.

The plant has certain branches which bear reproductive cells and other branches which are sterile. (Fig. 110.)

The **gamete plant** (the one bearing the gametes or reproductive cells) has an upright stem with a mass of pith in the center. The outermost portion is called the **cortex.** The cell walls in the cortex are thicker than those in the center and often contain pigment. The thickness of the cortex varies from two to four cells in thickness. The leaves are only one cell in thickness and never have a **mid-rib** or other **veins. In** other words, there are **no fibro-vascular bundles** in the stem at all. This is one of the great characteristics which distinguish this whole group of plants from the next higher grouping—the **Ferns.**

As the leaves mature, a goodly portion of the cells increase in size, the entire protoplasm being added to the walls of the cell so that these become very thick. This leaves the cell filled with nothing but air and water. In fact, this **hygroscopic** ( ) **ability** of the cells is the reason florists use the sponge-like **Sphagnum** in packing flowers for shipment.

In those branches which are set aside for reproductive purposes, each sex uses individual branches for the **antheridia** (male branch) and the **archegonia** (female branch), (Fig. 111). In some species, entire plants are of one sex or the other. In these, therefore, antheridia and archegonia are never found on the same plant. Such plants are said to be **dioecious** (from two households), while those plants on which both male and female reproductive branches appear are said to be **monoecious** (from one household).

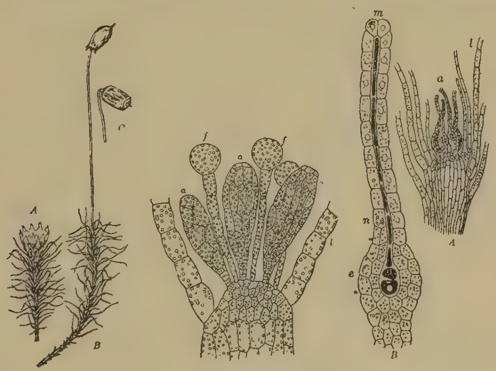

Fig. 111. Antheridia and Archegonia.

A Common Moss (*Polytrichum commune*). *A.*, male plant, showing cup-like tip containing the antheridia. *B.*, female plant with the sporophyte; *cal.*, cap, or calyptra, over the developing spore case; *C.*, a mature spore case with the calyptra removed.

Section Through the Tip of the Male Plant of a Moss (*Funaria*). *a.*, antheridium; *f.*, sterile filament, or paraphysis; *l.*, leaf.

Section Through the Tip of a Female Plant of a Moss (*Funaria*). *A.*, group of archegonia *a.*; *l.*, leaf. *B.*, an archegonium in detail, showing enlarged basal portion *e.* with the egg, and the neck *n.* above with its row of canal cells; *m.*, mouth. (After Sachs.)

(From Bergen & Davis' "Principles of Botany," by permission of Ginn & Co., Publishers).

The branches bearing antheridia are called **antheridophores.** An antheridium is found in the **axil** ( ) of each leaf of the head and consists of a stalk composed of not more than four rows of cells. When the antherium is mature it contains many sperm.* (Fig. 112.) The sperm are coiled, and bear two long thread-like cilia at their anterior end. There is a small appendage called a vesicle which contains starch granules. As the antheridia ripen, the sperm-sac is forced open and the sperm discharged. It is important that this **sperm-sac** be not confused with the **spore-capsule** to be mentioned later.

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*Botanists use "sperms" for the plural of "sperm," while zoologists do not. We have, therefor, kept the term "sperm" throughout as meaning both singular and plural.

The branches bearing archegonia are called **archegoniophores** and are usually found toward the upper portion of the plant, while the archegonia themselves are at the tip of the archegoniophores. (Fig. 113.) Each archegonia has a **neck, neck-canal,** a **venter** which contains the egg, and a **basal** or **pedicel.** The archegonia of ferns will be found to be quite like this, except that the pedicel is missing. Usually, several archegonia are found on a single branch. A number of enlarged leaves surround the archegonia. They constitute a **perichaetium** ( ).

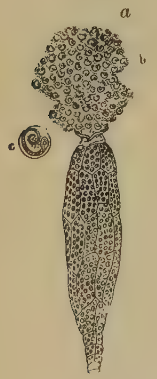

Fig. 112.
The Antheridium of a Common Moss (*Funaria*).
a., Antheridium; *b.*, escaping sperms; *c.*, a single sperm in its parent cell. (After Sachs.)

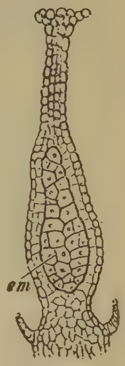

Fig. 113.
Archegonium of *Sphagnum*, showing a young embryo sporophyte (*em.*) developing in the venter. (After Schimper.)

Both archegonial and antheridial branches begin growing close together but the main branch from which both develop continues growing between them and separating them further and further.

Fertilization probably occurs in winter as young embryos are found in abundance in the spring. A film of water is needed for this purpose

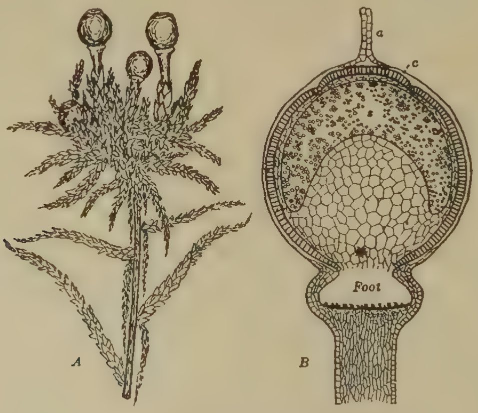

Fig. 114. The Sporophyte of the Peat Moss (*Sphagnum*).
A., group of the sporophytes on stalks, which are really growths from the gametophyte. *B.*, longitudinal section through a sporophyte, showing the large foot imbedded in the top of the stalk; *a.*, the remains of the parent archegonium, with the neck still present; *s.*, a spore chamber; *c.*, cover. (From Bergen & Davis' "Principles of Botany," by permission of Ginn & Co., Publishers.)

because sperm must swim to the neck-canal and pass through this into the venter. Here it enters the **egg** and the nuclei of sperm and egg unite. The fertilized egg now divides by mitosis very rapidly, the upper cells form a large **globular spore-case** with a thick central column within known as the **columella.** This is surrounded by a dome of spores, around which the wall of the sporangium is formed. The spore-case later pushes against the wall of the archegonium by enlarging. The wall is then ruptured, the top portion remaining as the **calyptra** ( ), (Fig. 119), while the spore case later opens by means of a lid. The lower cells produced by the dividing oösperm becomes a swollen **foot,** which is imbedded in the tissues below. It remains connected with the spore-case by a short stalk.

The structure which thus develops from the fertilized egg-cell is called the **sporophyte** (Fig. 114) stage of Sphagnum. In fact, all such simple plants which develop spores are called **sporophytes.**

Simultaneously with the maturing of the sporophyte, the apex of the female branch elongates into a leafless stalk about half an inch or more in length, known as the **pseudopodium.** It is supposed that the reason that the pseudopodium and sporophyte grow thus simultaneously is probably due to the cells in the foot secreting a substance which stimulates the cells in which it is imbedded to divide and enlarge, resulting finally in the formation of the pseudopodium. The advantage the plant gains is that the spore-case is raised to a higher plane and it can thus throw its spores much farther than would otherwise be the case.

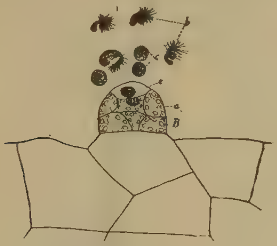

Fig. 115.

Antheridium of *Pteris* (*B.*), showing wall cells (*a.*), opening for escape of sperm mother cells (*e.*), escaped mother cells (*c.*), sperms free from mother cells (*b.*), showing spiral and multiciliate character. (After Caldwell.)

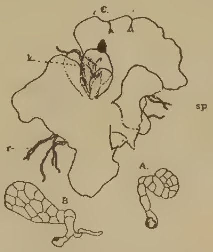

Fig. 116. *Sphagnum sp.*

A., *B.*, young protonemata; *C.*, older protonema with leafy bud, *k.*; *r.*, marginal rhizoids. (After Campbell.)

As **Sphagnum** possesses no chlorophyl, it does not manufacture its own food and must therefore live on the absorption of food-matter from the gamete plant through the foot.

The spores themselves develop in the following manner. (Fig. 115.) In the spore-case the inner cells differentiate into two kinds, one making up the larger portion of the tissues, and the other larger and richer in protoplasm, forming a dome of **sporogenous** or **spore-forming tissue** near the upper wall. It is from this latter type of cell that the **spore-mother-cells** are developed.

These spore-mother cells are divided twice, thus producing four spores each, and it is these spores which eventually **germinate** and produce the **gametophytes.** In ferns, we shall see that a quite similar process of spore formation takes place.

During the time the spores are **maturing,** a circular groove, called an **annulus,** forms near the **apex** of the spore-case. The cells in this region have thinner walls than the surrounding cells. These cells later become dry, and the thinnest part becomes torn to form a lid or **operculum** ( ) at the summit of the spore-case. As the operculum falls away, the sperm are dispersed.

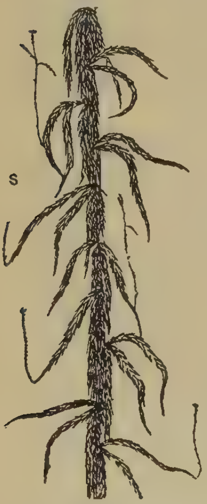

Fig. 117.
Sphagnum Cuspidatum, showing innovation, or short, branches. (After Schimper.)

If they find suitable soil a short green **protonema** (Fig. 116) germinates The tip of the protonema broadens to form the prothallus which is one cell in thickness. Tiny **rhizoids** ( ) form on the under side and from the margin, while other threads containing chlorophyl then develop. Often a thallus forms at the tip of each of these threads. From this thallus a leafy branch grows upward and the sphagnum plant described is again a full-fledged adult organism. The plant, from the time it germinates from the

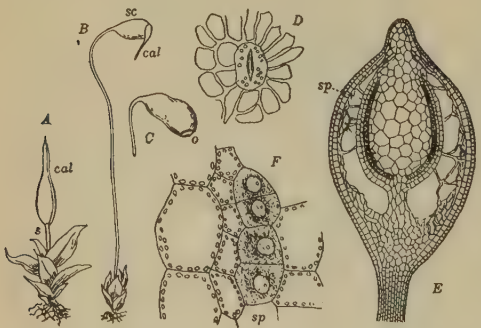

Fig. 118. I.
The Sporophyte of a Common Moss (*Funaria*).

A., young sporophyte *s.* attached to the leafy moss plant and covered by the calyptra *cal.* *B.*, sporophyte with mature spore case *sc.* and calyptra *cal.* at the tip. *C.*, spore case with calyptra removed; *o.*, the cover (operculum). *D.*, a stoma from the surface of the spore case. *E.*, section of young spore case, showing the cylindrical central region of spore-producing tissue *sp.* F., the spore-producing tissue in detail. (From Bergen & Davis "Principles of Botany," by permission of Ginn & Co., Publishers.)

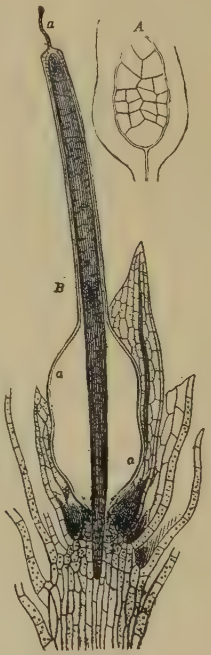

Fig. 118. II Developing Sporophytes of a Common Moss (*Funaria*).

A, very young stage, showing the early cell divisions of the egg; *B.*, older sporophyte just before the archegonium *a.* is torn away from the gametophyte and carried upward as the calyptra. The base of the sporophyte has now grown down into the tip of the leafy moss plant (gametophyte) and is firmly anchored to it. (After Sachs.)

spore until the thallus develops, is the **gametophyte**. This is to be distinguished from the adult plant which, as we have seen, is called the sporophyte.

There is an **asexual** multiplication of Sphagnum also. This is brought about by a sterile branch developing more powerfully than the surrounding ones. Then, each year, as the old stem dies off below, the young branch becomes a new plant. Sometimes little plantlets, known as **innovation branches** (Fig. 117), strike root and become independent plants. These innovation branches spring from close to the tip of the sterile branches.

The life-cycle of Sphagnum may be summarized as follows:

OUTLINE OF LIFE HISTORY OF SPHAGNUM

Sphagnum-plant **(gametophyte)**

Antheridial branch — Archegonial branch

Antheridia — Archegonia

Sperm (male gamete) — Egg (female gamete)

Fertilization

Oosperm (zygote)

Embryo

Mature Sporophyte

Sporangium

Spore-mother-cell

Spore Spore Spore Spore } **Reduction**

Protonema

Thallus

Sphagnum-plant **(gametophyte)**

The so-called **true mosses** (Fig. 109) have life-histories quite like that of Sphagnum, although there are differences. In true mosses the protonema produces leafy branches (the true moss-plants), but it does not produce a thallus. The leafy branches arise directly from the filamentous protonema. True mosses are both monoecious and dioecious. There is no pseudopodium (Fig. 118), but the stalk of the sporophyte which is very short in Sphagnum, here elongates to form a **seta,** often more than an inch in length.

The true mosses have little breathing pores called **stomata** at the base of the capsule. Sphagnum has the stomata, but they do not function. Chlorophyl-bearing cells surround these stomata, so that in the true-mosses there is some food actually manufactured by photosynthesis.

The sporophyte of the true mosses seems to occupy an intermediate position between Sphagnum and the next higher group of plants, the Ferns. There is an increase in sterile tissue as we approach the ferns, and a decrease in fertile tissue in the sporophytes.

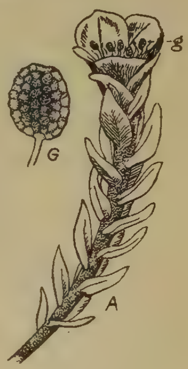

Fig. 119.

A Moss (*Tetraphis sp.*), showing gemmæ; *G.*, a gemma enlarged. (From C. Stuart Gager's "Fundamentals of Botany," by permission of P. Blakiston's Son & Co., Publishers.)

From experiments so far performed it seems that every cell of the moss-plant can, like the tissue-animal Hydra, which we shall soon study, develop a protonema—that is, each cell is **a potential spore.** Each protonema produces buds which become mature plants.

There are certain species of mosses in which the leafy-shoot, and in others, the **protonemata,** give rise to a special type of small bodies called **gemmae** (Fig. 119), ( ), which become separated from the parent plant and give rise to new plants.

A comparison of Sphagnum and a fern (to be studied next) is of value here.

The commonly known "fern-plant" is a **sporophyte** while the Sphagnum-plant is a gametophyte.

The fern sporophyte is dependent on the gametophyte for nutrition, at first, then the sporophyte becomes entirely independent, while the simple gametophyte perishes.

The Sphagnum sporophyte is the simpler plant and it is this sporophyte which must depend upon the gametophyte for nutrition throughout its entire life.

Reproduction is quite alike in Fern and Sphagnum. Each produces haploid gametes of two sexes, which then unite in fertilization, the zygote being diploid. It is the zygote which produces the spore-bearing phase. The spores, which are in turn haploid due to a reduction having taken place, then give rise to the haploid gametophytes, so that we may sum up the life-cycle in both Fern and Sphagnum by saying: Gametophyte alternates with sporophyte, fertilization with reduction, gametes with spores, haploid cells with diploid.

It will be seen from what has been said that this whole group of plants shows a **differentiation of cells into tissues,** while in the higher forms leaf-like structures appear. Then the **rhizoids** (specialized absorbing organs) are developed, and the plant tissues themselves contain chlorophyl. It is supposed that bryophytes have evolved from **aquatic forms** to **land forms** and consequently, as parts of the plant have dried, various **structural adaptations** ( ) have been brought about.

PTERIDOPHYTES

These are the Ferns (Fig. 120) and their allies in which the distinguishing feature is that these plants possess nearly everything that thallophytes and bryophytes possess, **plus a conducting or vascular system.**

These plants are supposed to have arisen "from a bryophyte ancestry where the sporophyte (sexless) generation, in some plants capable of doing chlorophyl work, developed a root system and vascular tissue, and taking the land habit, became independent of the gametophyte. This was one of the most important forward steps in the evolution of the higher plants, for it gave the sporophyte complete freedom to live and grow to its maximum size. This change marked a turning point in plant evolution, for, after the sporophyte became the most complex and conspicuous phase of the life-history, the gametophyte grew less prominent, until in the seed-plants the sexual generation became actually dependent or parasitic upon the asexual generation. This is a relation which is exactly the reverse of that which exists between the gametophyte and sporophyte in the liverwort and mosses."

"After the sporophyte became independent of the gametophyte, the next important advance was the development of the lateral spore-bearing and vegetative organs called **fronds** ( ). Then came the differentiation of the frond into vegetative **leaves,** given up entirely to chlorophyl work, and spore-leaves (sporophyls) devoted chiefly or wholly to spore production. With this also, came the massing of the sporophyls into **cones,** which was really the beginning of the structures called flowers in seed plants."

The pteridophytes have **underground stems (root-stocks or rhizomes)** so that only the leaves appear above ground. There is a **terminal bud** at the tip of the fern-stem. The **rhizome** bears **true roots** and its **tissues are differentiated** into **epidermal, fundamental, mechanical,** and **conducting systems.** In the tropics there are tree ferns, many of which have been found among the fossil plants.

The **spore-cases** grow in groups called **sori** ( ) on the **underside of the leaves** (Fig. 121). As the **annular ring** about each individual spore-case dries up, that side which is thinnest and has become dried most, splits open, throwing out the spores. There are usually 64 in each **sporangium.** These spores drop about the moist earth and grow into a **minute plant,** by first absorbing moisture, and then as the osmotic pressure becomes too great on the inner portion of the spore it breaks, sending out a tiny tube (Fig. 122). This process is called **germination** ( ). Then a smaller tube appears close to the spore body, but from the tiny tube, mentioned above,

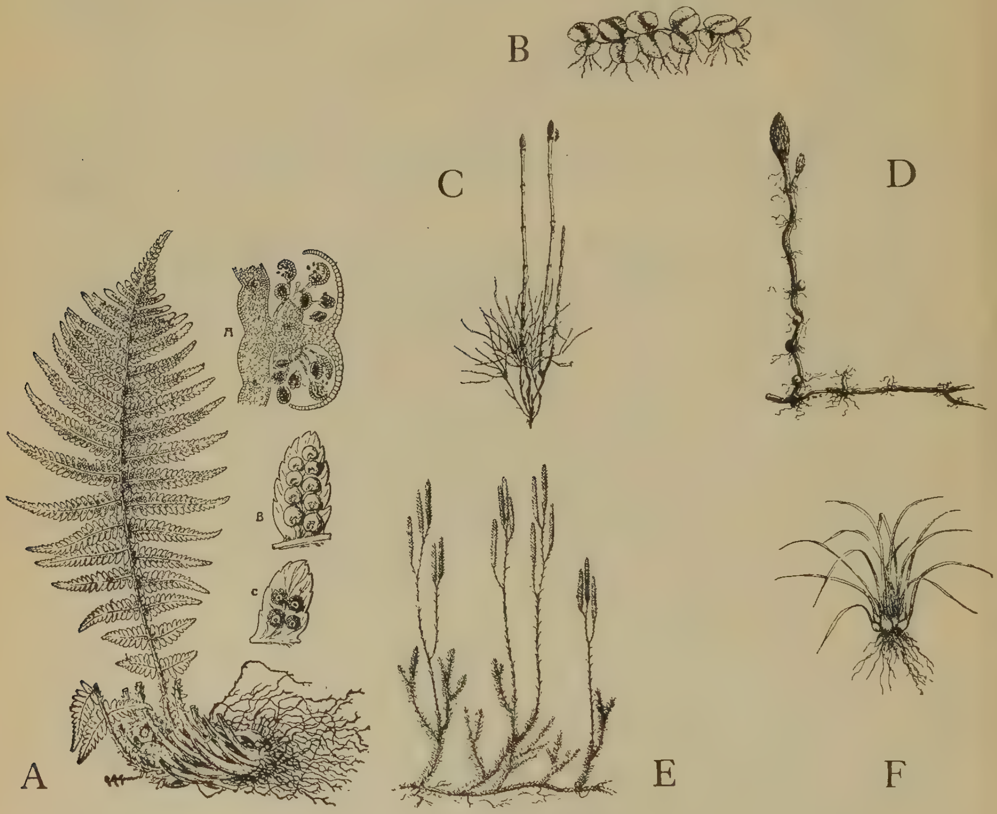

Fig. 120. The Ferns and Their Allies.

A. Fern plant (Aspidium), showing roots, rhizome, and frond: *A.*, section of fruit dot (sorus), showing spore cases, some of which are ejecting their spores; *B.*, portion of a leaflet, showing unripe fruit dots; *C.*, portion of a leaflet, showing ripe fruit dots. (After Strasburger.)

B. Order I. Salviniales (Floating Allies of ferns). *Salvinia natans.*

C. Order II. Equisetales. Branched Equisetum. *Equisetum Funstoni,* commonly called "Scouring Rushes," as distinguished from the "Horsetails" (also called Equisetales). The stems of Horsetails die each year and the fruiting cones have no terminal point.

D. Field Horsetail, showing buds and tubers.

E. Order III. Lycopodiales (Club-mosses). Common Club-moss, *Lycopodium clavatum.*

F. Order IV. Isoetales (Quillworts). Braun's Quillwort, *Isoetes echinospora Braunii.*

(A, after Strasburger; B to F, from W. C. Clute's "The Fern Allies," by permission of The Frederick A. Stokes Co.)

and this is the beginning of the root-like bodies, the rhizoids, which are to hold the plant in place and absorb moisture and food material from the ground.

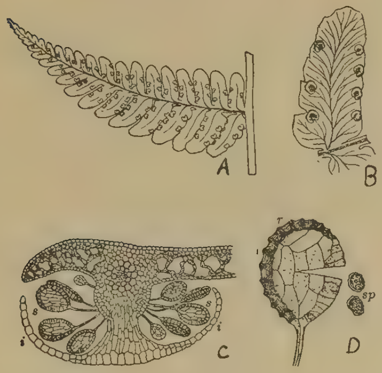

Fig. 121.

A., a leaflet of the frond viewed from below to show the position of the sori. *B.*, details of the sori and veining on a portion of a leaflet. *C.*, section of a sorus; *i.*, indusium; *s.*, sporangia. *D.*, a spore case or sporangium, showing the opening from which the spores (*sp.*) have been discharged; *r.*, ring. (From Bergen & Davis' "Principles of Botany," by permission of Ginn and Co., Publishers.)

This minute plant developing from the spore is called the **prothallium** ( ). It is **often heart-shaped** with a portion just posterior to the notch called the **cushion, several cells thick,** and the outer part called **the wings** which are **only one cell** in thickness.

Near the notch of the heart, close to the cushion, several flask-shaped bodies, the **archegonia** are formed. Each archegonium contains an egg cell. **Among the rhizoids** are the **sperm gonads** called **antheridia** ( ). Many tiny **motile cells** are found in the antheridia at maturity, but as these are discharged and find a small amount of moisture they reach the egg and fertilize it.

It will thus be seen that here, too, as in the mosses, there is an alternation of generations, the ordinary Fern being the asexual plant and the prothallus the sexual.

SPERMATOPHYTES

This group includes the plants which bear flowers like the rose and lily, as well as such flowerless groups as the pines which have their reproductive organs in cones or clusters, and are by no means so conspicuous as are those contained in a real flower.

Two older groupings of these higher plants are:

Phanerogams ( ). (The flowering plants.)
Cryptogams ( ). (The non-flowering plants.)

This grouping is one that came into existence before the sexual processes of plants had been studied to any extent, and so is not accurate, because the so-called **hidden** processes of the Cryptogams is in reality more evident than those of the complicated Phanerogams. As the **seed** is the **all-important part of a plant** from the reproductive point of view, the name **spermatophyte** has become popular. Seed plants, like Ferns, are **sporophytes,** though there is a **gametophyte generation** in their life-history, but it is so reduced in structure that it is quite difficult to see. The seed must, therefore, be studied.

It can readily be understood that the seed having a hard covering, which is wonderfully adapted for a protective purpose, lends itself well

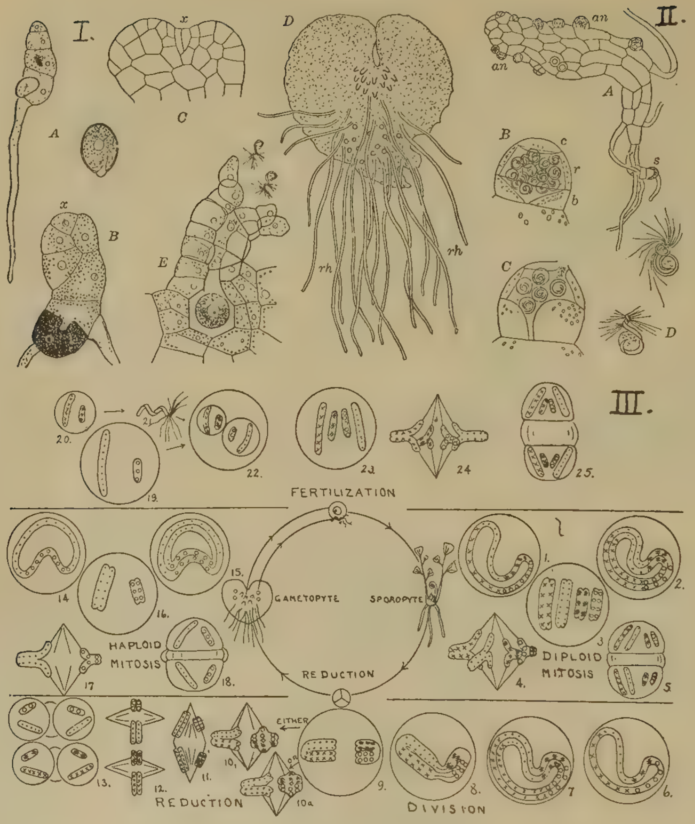

Fig. 122.

I. The Fern Prothallium and Archegonium.

A., stages in the germination of the spore. *B.*, young prothallium, showing first appearance of wedged-shaped, apical cell *x*. *C.*, tip of prothallium beginning to take on the heart-shaped form; *x.*, apical cell. *D.*, mature prothallium, showing group of archegonia on the cushion just back of the notch, and antheridia further back: *rh.*, rhizoids. *E.*, an open archegonium with egg ready for fertilization, and two sperms near the entrance of the neck. (*A.*, *B.*, *C.*, *E.*, after Campbell; *D.*, after Schenck.)

II. The Antheridium and Sperms of a Fern (*Onoclea*).

A., small prothallium with many antheridia *an.*: *s.*, old spore wall. *B.*, antheridium, showing cover cell *c.*, ring cell *r.*, and basal cell *b.*, inclosing the sperm mother cells. *C.*, antheridium opening. *D.*, *sperms.* (After Campbell.)

III. Diagram of a cytological life-cycle, based on a hypothetical fern with four chromosomes in the sporophyte. The nuclear phenomena are based on those of the thread-worm (*Ascaris*). Each chromosome is designated by a characteristic mark so that it may be traced throughout the diagram. (After R. F. Griggs).

to long vitality, and makes it possible for the **embryo** to develop so far within its protective covering that it can take root and establish itself readily when the time is ripe. Then, too, the seed is a storage organ of condensed food for the embryo.

The **pollen grain** of seed plants produces a **male gametophyte** which bears either sperm or sperm nuclei.

In the **ovule** of seed plants there is a **megaspore** which produces an embryo sac in which the egg is formed. The pollen grain produces an

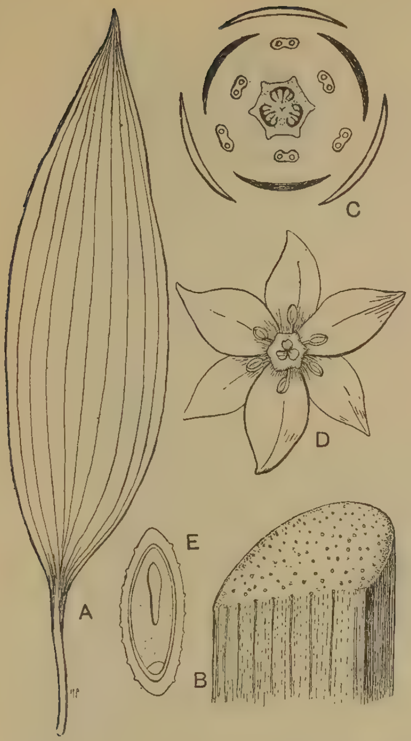

Fig. 123.—Morphology of typical monocotyledonous plant. *A*, leaf, parallel-veined; *B*, portion of stem, showing irregular distribution of vascular bundles; *C*, ground plan of flower (the parts in 3's); *D*, top view of flower; *E*, seed, showing monocotyledonous embryo. (From C. Stuart Gager's "Fundamentals of Botany" by permission of P. Blakiston's Son & Co., Publishers.)

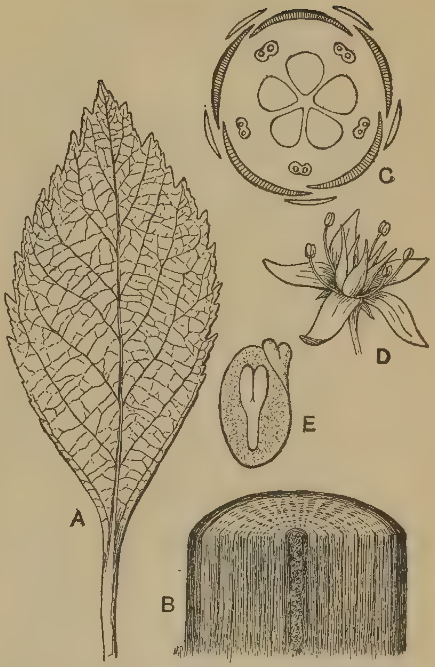

Fig. 124.—Morphology of a typical dicotyledonous plant. *A*, leaf, pinnately-netted veined; *B*, portion of stem, showing concentric layers of wood; *C*, ground-plan of flower (the parts in 5's); *D*, perspective of flower; *E*, longitudinal section of seed, showing dicotyledonous embryo. (From C. Stuart Gager's "Fundamentals of Botany" by permission of P. Blakiston's Son & So., Publishers.)

outgrowth or pollen tube which penetrates the tissues surrounding the egg and thus the sperm is carried to the egg, fertilizing it.

Seed plants are commonly divided into

Monocotyledons ( ) example, lilies, corn and grasses. (Fig. 123.)

Dicotyledons ( ) example, beans and cotton. (Fig. 124.)

The drawings of various stem cross sections will illustrate the difference in the structure of the two types of seed plants. (Fig. 125.)

Angiosperms.—In this type of plant the ovules are produced in a **closed** ovary composed of one or more **carpels** ( ). The ovules become seeds, and the carpels and surrounding parts are what constitute a **fruit.** This fruit may consist of the **ripened ovary only, or it may include the calyx** ( ) **and receptacle also.**

As no seed can be formed unless the reproductive organs, stamen

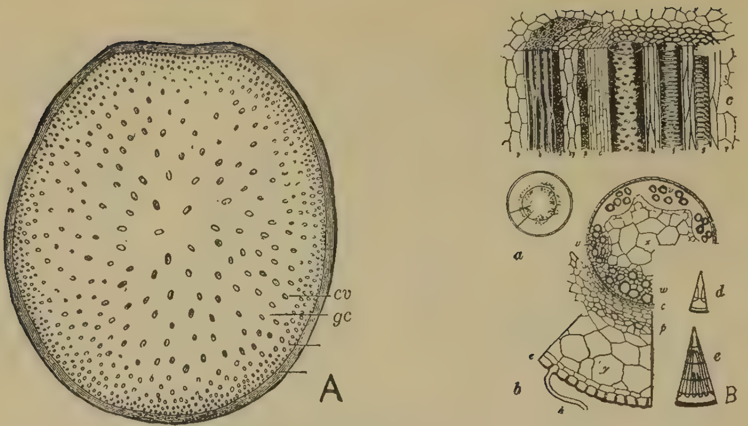

Fig. 125. *A*.—Diagrammatic Cross-section of Stem of Indian Corn (endogenous or Monocotyledonous Plant). *cv*, fibro-vascular bundles; *gc*, pithy material between bundles. *B*, Diagrams of stem sections (exogens or dicotyledonous plant). *a*, cross-section of chickweed stem, the inner circle representing the cambium ring, the two radial lines indicating the portion enlarged in *b*; *e*, epidermis; *h*, hair; *c*, cambium-separating between *p*, phloem and *w*, woody portions of bundles; *v*, spiral vessels in the woody portion; *x*, pith and *y*, common parenchyma of bark; *c*, segment of a sunflower stem; *p*, parenchyma; *b*, bast fibres; *s*, sieve tube; *c*, cambium; *g*, vessels, pitted and spiral; *h*, wood fibres; *d*, one year, and *e*, four year old woody stems, illustrating the increase of vascular bundles. (From Needham's "General Biology" after Wettstein, by permission of The Comstock Publishing Co.)

( ) and **pistils** ( ) are present, these are called **essential organs,** and plants having both in a single flower are called **perfect flowers,** while those having only **one or the other essential organs** are called **imperfect.**

If a flower possess in addition to the essential organs a **calyx** ( ) and a **corolla** ( ), it is called a **complete** flower.

All of these parts are better understood from a study of Figure 146 than from any description that could be given.

PLANT HISTOLOGY

A correct understanding of plant tissues can, however, come only from a knowledge of how such tissues develop.

Just as we shall soon see, hydra (because it is composed of tissues only) can regenerate almost any portion of the body, so, too, the early embryonic substance of plants is all quite alike, and can develop into many and varying types of cells. This early undifferentiated embryonic plant tissue is known as **meristem.** It is from this meristem that the so-called **primary tissues** develop. However, in the early embryo, even while all the cells are quite alike, it is possible to suggest a division into three zones (Fig. 126), in each

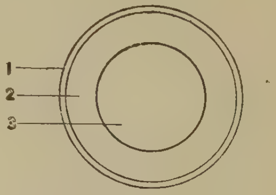

Fig. 126.

Three Growth Zones, showing arrangement of the Fundamental Tissue Layers in roots and stems. 1, Dermatogen zone. 2, Periblem zone. 3, Plerom zone. (After C. W. Ballard's "Vegetable Histology," Courtesy of John Wiley and Sons).

of which certain particular structures will ultimately grow.

The diagram shows an outer, or **dermatogen region**, a more interior or **periblem region**, and an innermost, or **plerom region.** It is in the dermatogen zone that the **first covering-tissues** develop, while the periblem zone gives rise to the **covering-tissues of the mature plant.** All other structures arise in the plerom zone.

The original cell-masses which constitute the three zones mentioned above, are known as **fundamental tissues** up to the time the **primary tissues** can be seen.

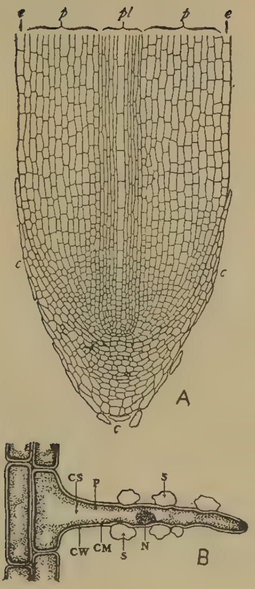

Fig. 127.

A, longitudinal section through the root tip of spiderwort, showing the plerome (*pl*), surrounded by the periblem (*p*), outside of periblem the epidermis (*e*) which disappears in the older parts of the root, and the prominent root-cap (*c*). (After Land.)

B, diagram of a root hair: *CM*, cell membrane; *CS*, cell sap; *CW*, cell wall; *P*, protoplasm; *N*, nucleus; *S*, soil particles.

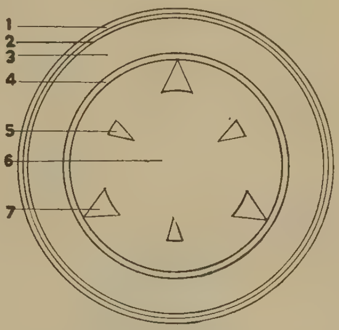

Fig. 128. Arrangement of the Primary Tissues in the Root.

1. Epidermis. 2. Hypodermis. 3. Primary Cortex. 4. Endodermis. 5. Xylem bundle. 6. Pith. 7. Phloem bundle. (After C. W. Ballard's "Vegetable Histology." Courtesy of John Wiley and Sons).

In the dermatogen of the root, **three distinct primary tissues** develop. The outermost layer at the root-tip (Fig. 127) is the **root-cap.** This becomes thickened and protects the more delicate structures as the process of growth forces the root-cap through the soil.

The epidermal cells above the root-cap give rise to **root-hairs,** which are important **absorption organs.**

Above that portion of the root, which is covered with root-hairs, there are thick-walled epidermal cells. These form the **primary epidermis.**

In the periblem zone there are also three primary tissues. (Fig. 128.) The layer bordering on the primary epidermis is known as the **hypodermis** (   ). This layer is made up of thick-walled cells which are usually angled. The layer joining the plerome zone is the **endodermis** ( ). The cells in this layer are also thick-walled and resemble those of the hypodermal layer. Between hypodermal and endodermal layers there are several layers of cells which constitute the **primary cortex** or **cortical parenchyma** ( ).

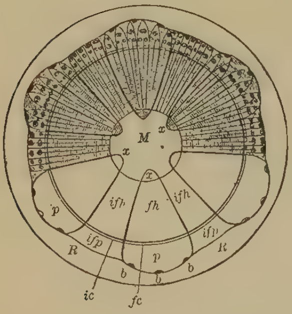

Fig. 129.

Diagram to illustrate secondary growth in a dicotyledonous stem which takes place in the plerome zone.

R, the first-formed bark; *p*, mass of sieve cells; *ifp*, mass of sieve cells between the original wedges of wood; *fc*, cambium of wedges of wood; *ic*, cambium between wedges; *b*, groups of bast cells; *fh*, wood of the original wedges; *ifh*, wood formed between wedges; *x*, earliest wood formed; (*c*). (After Land.)

The cortical parenchyma is made up largely of undifferentiated original periblem tissue.

It is in the plerom zone (Fig. 129) where the most striking changes in the cell walls take place. Groups of cells have their walls thickened by the deposition of lignin ( ), which forms the fibrous elements that give strength to the plant. Such fibrous elements are known as **prosenchyma** ( ). The **conducting elements** are developed in the midst of these lignified cells.

Each group of lignified cells, together with its associated ducts constitutes the **xylem** ( ). This is usually arranged in a very definite order in the plerom region. There are other cells forming tubes, also in the plerom zone. The end walls of these cells are perforated. These form the **sieve tubes**. Each group of sieve tubes with its associated companion cells, parenchyma cells, and lignified tissue, constitutes the **phloem** ( ). These bundles are also often arranged in a very definite order.

The lignified cells of xylem are called **wood fibers** (Fig. 130), and the lignified cells of phloem are called **bast fibers.**

Xylem and phloem are made up of both **fibrous** and **vascular** (conducting) elements to form **fibro-vascular bundles.**

The xylem and phloem are located in a circle near the outer boundary of the plerom region, and as they begin to develop, usually alternate with one another.

As there are narrow strips of unchanged plerom parenchyma extending between the fibro-vascular bundles, (Fig. 131) these strips present the appearance of rays, and consequently are known as medullary rays, while the unchanged parenchyma in the center of the plerom is the **pith.**

In many orders of plants it is these primary tissues which remain with but little change, throughout life, but in the higher orders these primary tissues change to **secondary** or permanent tissues. (Fig. 132.)

The epidermis is replaced by a **bark structure** which originates in the periblem region.

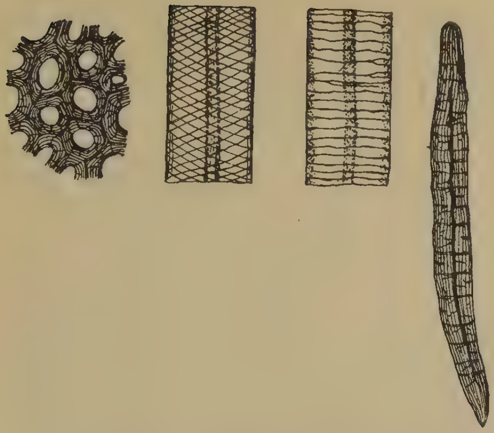

Fig. 130. Types of Wood and Bast Fibers.

A, cross section of bast fibers from stem of *Aristolochia Sipho* showing stratification. *B*, Portion of bast fiber, showing oblique striation. *C*, Portion of bast fiber showing transverse striation. *D*, Bast fiber from the bark of *Cinchona Calisaya*, showing longitudinal striae and small tubes connecting the lumen of the cell with the exterior. (From Bastin's "College Botany." Courtesy of G. P. Engelhard & Co.)

Some of the primary cortical cells become meristematic, thus constituting the **cork cambium** or **phellogen** ( ); these cells subdivide rapidly to form a new tissue on their outer surface. the cork, and on the inner surface, **phelloderm.**

Bark is everything outside of the true cambium (not the cork cambium), excluding the cambium and epidermis.

The phellogen retains its meristematic power throughout the entire life of the plant so that new protective tissues can keep pace with the internal growth.

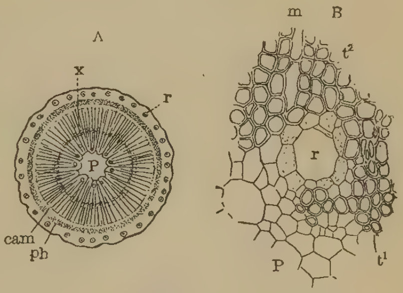

Fig. 131. Medullary Rays and Pith.

A, *Pinus Virginiana*, cross section of two-year-old branch. *P*, pith; *x*, wood, showing two annual rings; *cam*, cambium; *ph*, phloem; *r*, resin-ducts in the cortex. *B*, *Pinus insignis*, cross-section of the inner part of the wood. *P*, pith; *t*¹, primary tracheae; *t*², secondary tracheids; *r*, resin-ducts; *m*, medullary ray. (From D. H. Campbell's "A University Text-book of Botany," by permission of The MacMillan Co., Publishers).

The primary fibro-vascular bundles consist of xylem and phloem, but in the change to secondary structures, a meristematic tissue called **cambium** ( ) develops in connection with these. The cambium develops on the outer face of the xylem (Fig. 133), and on the inner face of the phloem, so that the cambium arc on each xylem bundle produces xylem on its inner face and phloem on its outer side. Similarly, the cambium arc on the phloem bundle develops xylem on the inner side and phloem upon the outer.

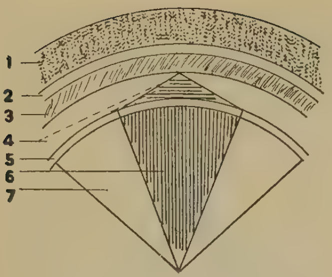

Fig. 132. Arrangement of Secondary Tissues in Roots and Stems.
1. Peridem (bark). 2. Phellogen. 3. Phelloderm (bark). 4. Phloem elements. 5. Cambium. 6. Xylem elements. 7. Medullary rays. Compare with Fig. 129. (After C. W. Ballard's "Vegetable Histology." Courtesy of John Wiley and Sons).

This causes each fibro-vascular bundle now to consist of xylem and phloem elements, separated from each other by a thin strip of cambium. Such bundles which have been completed by the cambium are called **complete fibro-vascular bundles,** while those not so completed are known as **incomplete fibro-vascular bundles.** (Fig. 134.)

As the cambium continues growing constantly, the plerom parenchyma becomes almost entirely replaced by xylem. The new fibro-vascular bundles develop in the broad primary medullary rays.

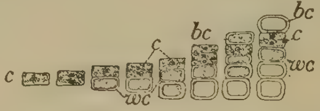

Fig. 133. Diagram Showing the Method by which the Cambium Layer Produces Wood Cells on its Inside and Bark Cells on the Outside.
bc, the cells of the bark; *c*, cambium cells; *wc*, the wood cells.

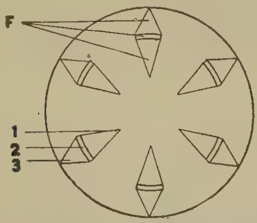

Fig. 134. Completion of Fibrovascular Bundles. *F*, Completed fibrovascular bundle. 1. Xylem elements. 2. Cambium. 3. Phloem elements. (From C. W. Ballard's "Vegetable Histology," Courtesy of John Wiley & Sons).

The stem and root development differ somewhat. There are no root hairs or root-caps on the stem. The primary stem epidermis often possesses **stomata** (breathing pores) while the root does not. The parenchymal cells of the stem often contain **chloroplasts** which the parenchymal cells of the root never do. Then, too, the root has no hypodermis (mechanical tissue immediately underneath the epidermis). There is usually no endodermis in the stem though there is in the root. The plerom zone of primary stems differs considerably from that of primary roots both in the arrangements and development of tissues. All fibro-vascular bundles in the plerom region of the primary stem are complete, showing phloem, xylem, and cambium elements throughout their entire period of growth. This means that the primary fibro-vascular bundles of the stem are really equivalent to the secondary bundles of the root. The primary stem structures described above serve throughout the life of the plant only, if such plant is an **annual.** In **perennials** ( ), a better and more durable covering tissue must be developed. In these the primary epidermis is replaced by periderm tissues which have been produced by a phellogen which in turn developed in the primary cortex. The periderm of stems is often ruptured and cast off as the inner tissue expands. This does not occur in roots. When such casting off takes place, the primary periderm is replaced by secondary periderm which develops directly from the original phellogen or secondary phellogen layers. The hypodermal and endodermal layers disappear as soon as the phellogen is formed in the primary cortex. The primary fibro-vascular bundles become larger by new xylem and phloem elements being added by the cambium and the cambium arcs extend until they become a complete ring or circle.

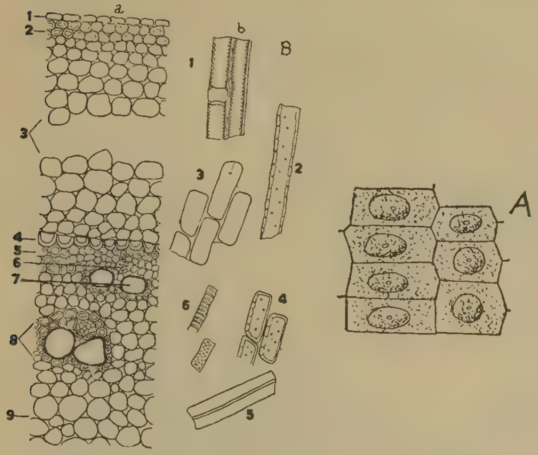

Fig. 135.

A. Early undifferentiated cells known as Embryonic or Meristem tissue.

B. The secondary (permanent) tissues are divided into parenchyma and prosenchyma. The former have thin walls and protplasmic contents. They are found in the undifferentiated cellular structures of all three zones in the embryo. They are usually spherical in shape, or at least "as broad as they are long." Prosenchyma cells are formed in the Plerom region of the embryo. They have thick walls and little or no cell content. The cells are usually long fiber cells with sharp-pointed ends.

a. Transverse Section, Triticum Rhizome. 1. Epidermis. 2. Hypodermis. 3. Cortical parenchyma. 4. Endodermis. 5. Fibers, surrounding sieve and ducts. 6. Sieve. 7. Ducts. 8. Concentric fibrovascular bundle. 9. Pith parenchyma.

b. Powdered Triticum Rhizome. 1. Epidermis. 2. Hypodermis. 3. Parenchyma, longitudinal view. 4. Endodermis. 5. Fibers. 6. Vessels. (From C. W. Ballard's "Vegetable Histology," Courtesy of John Wiley & Sons).

New fibro-vascular bundles form in the broad medullary rays extending between the original bundles while new woody elements are being added to the xylem. These woody elements, however, never entirely replace the original plerom tissue in the center of the stem. This unchanged central plerom tissue is the **pith.** As the plerom parenchyma is entirely replaced by woody tissues in roots, the presence of pith is valuable in distinguishing stem from root.

The secondary or permanent stem tissues are often divided into **parenchyma** ( ) and **prosenchyma. Parenchymal cells** may be found in all three zones of the embryo. They have thin walls and protoplasmic contents. **Prosenchymal cells** are formed in the plerom region of the embryo. They have thick walls, and the protoplasmic contents are very inconspicuous or even entirely lacking. While these distinctions are by no means absolute, they are of great importance. Further, prosenchymal cells are usually spindle-shaped while parenchymal cells are more inclined to be spherical or cubical with rounded corners. (Fig. 135.)

The final tissues are usually grouped according to their functions. They are:

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*Xylem and phloem both carry water, but the former carries food material as such, while the latter carries food in the water.

Covering or **Protective Tissues.** (Fig. 136.) **Epidermis** and **periderm.**

Supporting or **Mechanical Tissues.** (Fig. 137.) All fibrous tissues, such as wood and bast fibers, stone cells **(schlerenchyma),** polygonal cells with very thick cellulose walls, especially thick at the angles **(collenchyma)** which take the place of woody tissue in annual herbaceous or green stems, fruits, seeds, and leaves. Collenchyma is usually associated with the fibrous tissues in the midrib of leaves.

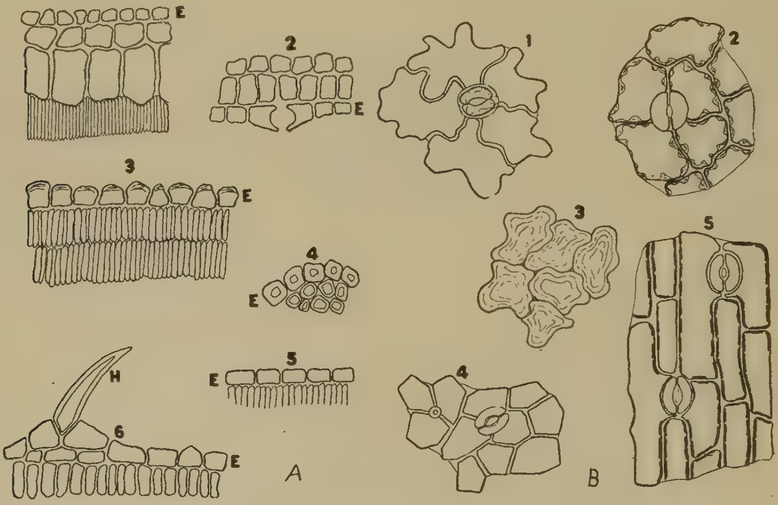


Fig. 136. Epidermal Tissues.

A, Sectional views of Leaf Epidermis. 1. Upper epidermis, Ficus leaf. 2. Lower epidermis, Ficus leaf. 3. Upper epidermis, Eucalyptus leaf. 4. Epidermis of Pine leaf. 5. Upper epidermis, Orange leaf. 6. Upper epidermis, Geranium (Pelargonium), leaf. *E*, epidermis. *H*, hair.

B, Surface views of Leaf Epidermis. 1. Hepatica leaf (wavy walls). 2. Chimaphilla leaf (beaded walls). 3. Henbane leaf (wavy and striated walls). 4. Senna leaf, angled cells). 5. Convallaria leaf (beaded walls). (From C. W. Ballard's "Vegetable Histology," courtesy of John Wiley & Sons.)

Absorption Tissues. (Fig. 138.) Root-hairs for liquids, and **stomata** (openings usually on the underside of leaves surrounded by two sausage-shaped guard-cells) and **lenticels** (openings in the periderm or corky coverings of mature woody plants).

Conducting Tissues. (Fig. 139.) **Ducts (tracheae** are continuous tubes formed by the absorption of the connecting cell's end-walls, and the disappearance of the cell contents.) These tubes may be **pitted** (when there are numerous pores through the cell wall), **reticulate** (when the lignin laid down on the inner side of the cell wall is in the shape of a network), **scalariform** (when the non-lignified portions of the cell walls form long narrow slits which are quite uniform). Such cells are often angled (no others are). **Annular** (thin-walled tubes with rings of lignified tissue within the lumen of the tube), and **spiral** (where the lignified tissue is arranged in the form of a continuous spiral-band, or collection of bands).

Tracheids are merely single cells which have lost their protoplasmic contents, but not their entire end-walls. Communication is carried on by pores in the vessel walls.

Sieve Tubes, unlike all the other ducts mentioned above, usually carry materials away from the leaves. They are merely individual cells whose end-walls have not completely broken down, as in the tracheids, but have formed sieve plates with many pores or perforations connecting one such individual cell with the next below, and so continuing for great lengths in the plant. The walls of sieve tubes are composed of cellulose, there being no trace of lignification.

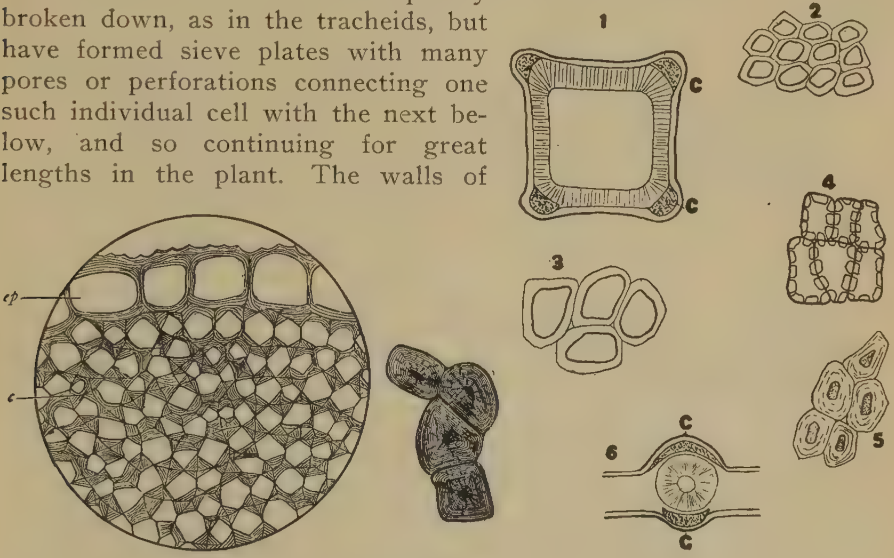


Fig. 137. Mechanical and Supporting Tissues.

These tissues consist of wood and bast fibers (See Fig. 130), *schlerenchyma* (stone-cells), and *collenchyma.*

A, Portion of epidermis and collenchyma from the stem of *Rumex crispus.* Cross Section, *ep*, epidermis; *c*, collenchyma.

B, Sclerotic cells from the root of Apocynum androsaemifolium. All highly magnified. (From Bastin's "College Botany" courtesy of G. P. Engelhard & Co.)

C, 1. Peppermint stem. Arrangement of collenchymatic (*C*), tissues at angles of the stem. 2. Peppermint stem. 3. Sabal seed. 4. Colchicum seed. (Porous type). 5. Nux Vomica seed. (Striated type). 6. Arrangement of collenchymatic tissues around the midvein of a leaf. *C*, collenchyma. (From C. W. Ballard's "Vegetable Histology," Courtesy of John Wiley & Sons).

Medullary Rays furnish the method by which material is transported from the inner-tube region of the plant, laterally, to the tissues which lie closer to the outside of the stem, and from these to the pith where food may be stored.

Latex Tubes. These are non-porous tubes in certain plants and contain a milk-like fluid.

Porous Parenchyma. In the pith region the parenchyma, which is very porous, may possibly assist in permitting the nutrients which are in solution to pass back and forth.

As already stated, each group of vessels with its connecting mechanical or supporting tissue forms a fibro-vascular bundle. These may be either complete or incomplete; complete, if they possess xylem, phloem, and cambium elements, and incomplete if they possess either xylem or phloem without the cambium element. The xylem is always supported by wood fibers and the phloem by bast fibers. There are five different arrangements of fibro-vascular bundles:

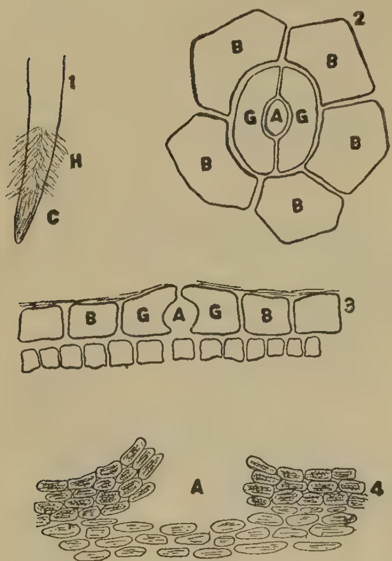


Fig. 138. Absorption Tissues.
1. Root hairs (*H*) on rootlet of germinating Fenugrek seed. *C*, root cap. 2. Stomata, surface view. *A*, breathing pore. *G*, guard cells. *B*, bordering, neighboring or surrounding cells. 3. Stomata, sectional view. *A*, breathing pore. *G*, guard cells. *B*, bordering cells. 4. Lenticel (*A*). (From C. W. Ballard's "Vegetable Histology," Courtesy of John Wiley & Sons).

(1) **Radial** (common in all young roots, and sometimes in mature monocotyledonous roots). These are always incomplete, consisting of either xylem or phloem. The xylem or phloem elements are arranged in a circle within the endodermis, a xylem bundle alternating with a phloem bundle.

(2) **Concentric fibro-vascular bundles** (common in monocotyledonous roots and stems), are bundles consisting of both xylem and phloem, so arranged that either the xylem surrounds the phloem or the phloem surrounds the xylem. The former arrangement is the more common. The bundles are irregularly scattered in the pith region.

(3, 4, and 5) **Collateral fibro-vascular bundles** are complete, having both xylem and phloem elements, as well as a cambium-arc. These are in turn divided into three types, known as **open, closed,** and **bi-collateral.**

(3) **Closed Collateral bundles** (usually found only in the pith of monocotyledonous stems and rhizomes and the leaves of all seed plants), are made up of a xylem portion and a phloem portion, never separated from each other by a strip of cambium.

(4) **Open Collateral bundles** (most frequently found in dicotyledonous roots and stems) are made up of xylem elements within a cambium zone and phloem elements on the outer side of the cambium.

(5) **Bi-Collateral bundles** (found in some dicotyledonous roots and stems) are made up of a xylem element and the associated cambium, but with two phloem elements, one on each surface of the xylem.

Assimilating and Synthesis Tissues (Fig. 140). The Chloroplasts

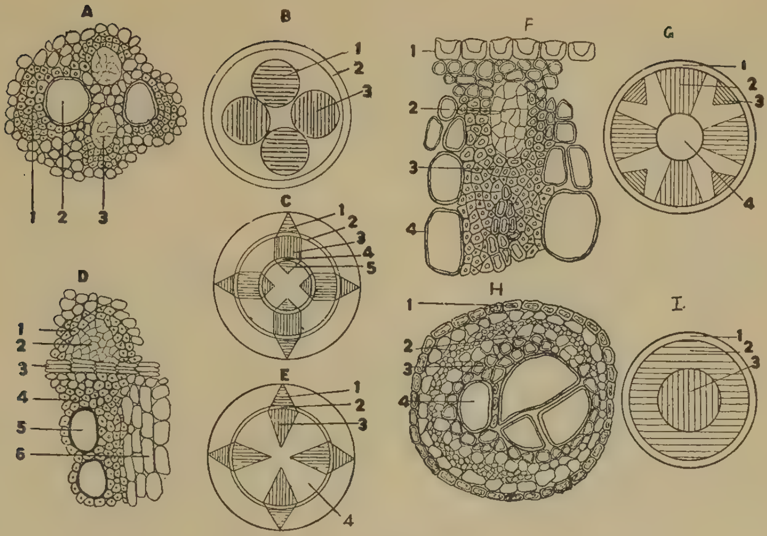


Fig. 139. Conducting Tissues.

A. Collateral type, Bamboo stem. 1. Fibrous tissue. 2. Ducts. 3. Sieve.
B. Collateral Bundle, arrangement of fibrovascular elements. 1. Xylem. 2. Endodermis. 3. Phloem.
C. Bicollateral Bundle, arrangement of fibrovascular elements. 1. Phloem. 2. Cambium. 3. Xylem. 4. Cambium. 5. Phloem.
D. Open collateral type, Aconite tuber. 1. Bast fibers. 2. Sieve cells. 3. Cambium. 4. Wood fibers. 5. Ducts. 6. Medullary ray.
E. Open Collateral Bundle, arrangement of fibrovascular elements. 1. Phloem. 2. Cambium. 3. Xylem. 4. Medullary ray.
F. Radial type, Sarsaparilla root. 1. Endodermis. 2. Sieve surrounded by bast fibers. 3. Wood fibers surrounding sieve and ducts. 4. Ducts.
G. Radial Bundle, arrangement of fibrovascular elements. 1. Endodermis. 2. Xylem. 3. Phloem. 4. Pith.
H. Concentric type, Fern rhizome. 1. Endodermal sheath. 2. Sieve surrounded by small parenchyma. 3. Fibrous tissues. 4. Ducts.
I. Concentric Bundle, arrangement of firovascular elements. 1. Endodermal sheath. 2. Phloem. 3. Xylem. (From C. W. Ballard's "Vegetable Histology," Courtesy of John Wiley & Sons).

(the tiny divisions in the cell of plants which contain chlorophyl), are important structures in synthesis by converting (when in the sunlight) carbon dioxide and other substances into starches and sugars; and the **Leukoplasts** (similar structures which do not contain chlorophyl), by assisting in forming storage- or reserve-starch from the sugar manufactured by the chloroplasts.

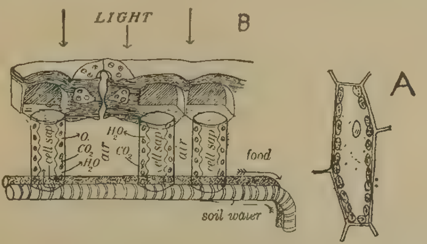


Fig. 140. Assimilating and Synthesis Tissues.
A. Plastids (chloroplasts) in a cell.
B. Diagram to illustrate the processes of breathing, food-making, and transpiration which may take place in the cells of a green leaf in the sunlight. (After Stevens).

Secreting cells and hairs which are really structures quite like the glands of animals.

Storage Tissues (Fig. 141). In plants which continue their life throughout many seasons, there must be a method of storing the food which is made primarily in the summer. The organs are the **Paren-**

chyma cells of the cortical and pith regions. Here the reserve starch made by the leukoplasts is stored, as also are many other plant nutrients.

Secretion cavities of various kinds carry oils and other products of gland cells.

Colenchyma cell walls, especially in seeds and fruits, contain much cellulose. This means that collenchymal cells are supporting and storage tissue as well as synthesis tissue.

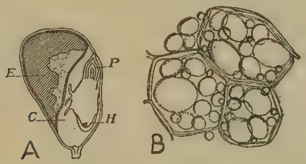


Fig. 141. Storage Tissues.

These are the parenchyma cells of the cortical and pith regions of the plant; the cellulose in the collenchyma cells (which makes collenchyma a synthesis, supporting, and storage tissue), and cavities of stone cells and fibers.

A, grain of corn, cut lengthwise; *C*, cotyledon; *E*, endosperm; *H*, hypocotyl; *P*, plumule.

B, starch grains in the cells of a potato tuber.

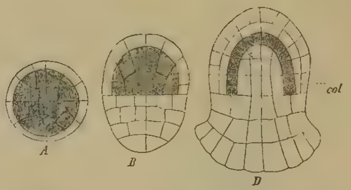


Fig. 142. Reproductive Tissues.

Diagrammatic sections of sporogonia of liverworts: *A*, *Riccia*, the whole capsule being archesporium except the sterile wall layer; *B*, *Marchantia*, one half the capsule being sterile, the archesporium restricted to the other half; *D*, *Anthoceros*, archesporium still more restricted, being dome-shaped and capping a central sterile tissue, the columella (*col*). (After Goebel).

Cavities of Stone cells and Fibers may contain nutrient material in a few cases, but in such instances it is not readily available for the plant.

Reproductive Tissue (Fig. 142). From inner tissues of anther and ovary in flowering plants.

When pollen is transferred from **anther** ( ) to **stigma** ( ) the process is called **pollination. Wind, insects,** and **water** are means by which **pollen is carried** from one plant to another. Bees are common carriers, and the remarkable way some plants are adapted to forcing any intruder to carry pollen with it, is one of the most astounding of all adaptations in nature (Fig. 239).

POLLINATION

Pollination can probably best be understood by considering the modern pines. In the common Scotch Pine (Fig. 143), **(Pinus silvestris)** the **microsporophyls** (called **stamens** in the flowering plants) are massed into cones about 1 centimeter in length, and these cones are in turn massed in clusters.

There are two sporangia on the lower surface of each microsporophyll. These **microspores** or **pollen** escape from the sporangia and are carried by the wind (often for many miles) to the **megaspore** (carpellate) **cones.**

The megaspore cones grow singly or in clusters near the ends of the upper twigs of the season's growth, and are also about one centimeter in length. There is a general axis on which flat megasporophyls are borne. Each of these megasporophyls bear two inverted **megasporangia** or **ovules** (Fig. 144).

The pollen falls between the **megasporophyls** (called **carpels** in the flowering plants), and each microspore then pushes out a **pollen tube** which penetrates the ovule tissue. This process stimulates the growth of the cone tissues and the cone, therefore, increases in size. The ovules also enlarge and the upper end of the ovule develops a thickened mass of green tissue which grows beyond the end of the sporophyl, to form the **seed scale.** These seed scales are merely the distal ends of the ovules, and function as organs of photosynthesis for a year or so.

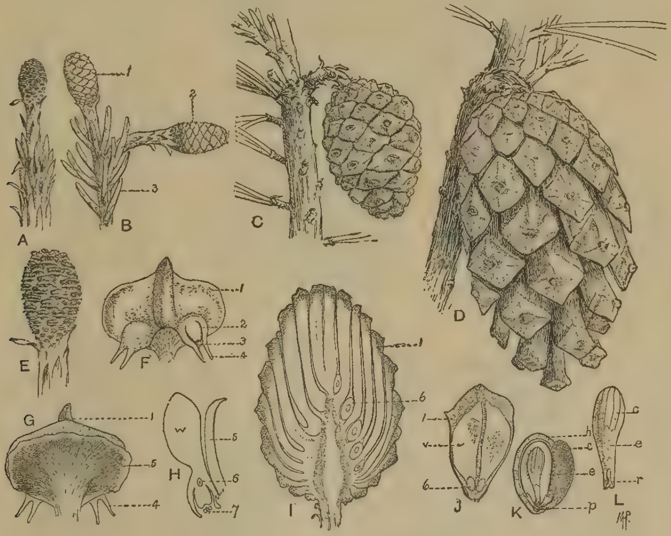


Fig. 143. Scotch Pine (*Pinus sylvestris*).

A-D, stages in the development of the carpellate cone, and its carpotropic movements. *E*, very young carpellate cone much enlarged; *F*, ventral, *G*, dorsal views of a scale from *E*; 1, ovuliferous scale; 2, ovule (in longitudinal section); 3, pollen chamber and micropyle leading to the apex of the nucellus (megasporangium); 4, integument of the ovule; *G*, 1, tip of ovuliferous scale; 5, bract; 4, integument; *H*, longitudinal section at right angles to the surface of the ovuliferous scale (diagrammatic); 6, megaspore; 7, pollen chamber, *I*, longitudinal section of a mature cone; 6, ovule; *J*, scale from a mature cone; 6, seed; *w*, wing of seed; *K*, dissection of mature seed; *h*, hard seed coat; *c*, dry membranous remains of the nucellus, here folded back to show the endosperm and embryo; *e*, embryo; *p*, remains of nucellus; *L*, embryo; *c*, cotyledons; *e*, hypocotyl; *r*, root-end. (From C. Stuart Gager's "Fundamentals of Botany," by permission of P. Blakiston's Son & Co., Publishers).

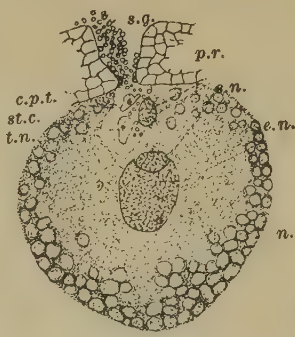
The following summer or autumn a **spore-mother-cell,** also known as an **archespore,** arises in the interior tissues of the ovule. This archespore then divides into four cells which are really four young megaspores, although only the one lying in the lowest position actually develops into a full-fledged megaspore.

This megaspore then divides and subdivides until a rather solid cellular mass is formed. This cellular mass is the **gametophyte.** (Fig. 145.)

It is from this gametophyte that several (usually four) sunken archegones arise. The completing process of fertilization may now take place.

After fertilization the gametophyte becomes stored with food and functions as the **endosperm.**

III



The pollen-tube has also resumed its growth by this time and has brought the two non-ciliated sperm to the mouth of an archegone. One of the sperm fuses with the egg which completes fertilization. This fertilization takes place in the pines more than a year after pollination.

The fertilized egg, now called a **zygote**, gives rise to the **embryo** consisting of a cylindrical stem with narrow whorled leaves and a

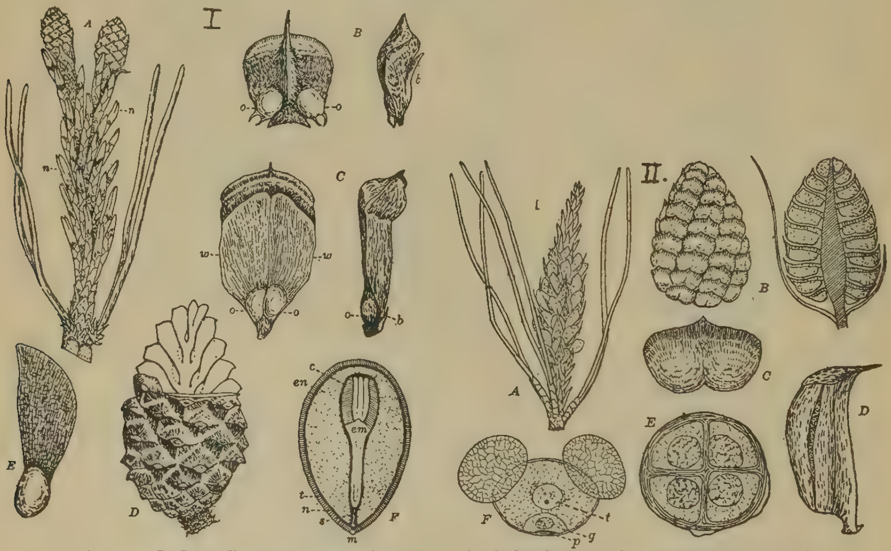


Fig. 144. I. Carpellate cone, carpels, and seed of the Scotch pine (*Pinus sylvestris*). *A*, young growth with carpellate cones, about three weeks after the opening of the terminal bud: *n*, young pine needles. *B*, inner and side view of a cone scale at the time of pollination as shown in *A*: *b*, bract; *o*, ovules. *C*, inner and side view of scales from a mature cone as shown in *D*: *b*, bract; *o*, fertilized ovules now rapidly maturing into winged seeds; *w*, the developing wings. *D*, a mature cone. *E*, a mature winged seed. *F*, section of mature seed; *t*, hard seed coat, or testa, developed from the integument of the ovule, *n*, a membranous seed coat which is the remains of the nucellus; *en*, endosperm or tissue of the female gametophyte; *em*, embryo with group of cotyledons *c* and the suspensor *s*; *m*, micropylar end of seed.

II. The staminate cone, stamen, and pollen of the Scotch pine (*Pinus sylvestris*). *A*, young growth, with staminate cones about two weeks after the opening of the terminal bud. *B*, details of cone. *C*, end view of stamen. *D*, side view of stamen. *E*, pollen mother cell developing four pollen grains in a tetrad. *F*, pollen grain showing the two wings; *p*, prothallial cell; *g*, generative cell; *t*, tube nucleus.—*E*, (After Miss Ferguson).

III. White pine.

(*Pinus Strobus*). Longitudinal section through an archegonium at the time of fertilization. Above the fusing nuclei are various other elements emptied into the egg from the pollen-tube. Collected June 21, 1898. × about 62. *s.g.*, starch grains; *p.r.*, prothallium; *c.p.t*, cytoplasm from pollen-tube; *st.c.*, stalk-cell; *t.n*, tube-nucleus; *s.n*, sperm-nucleus; *e.n*, egg-nucleus; *n.s*, nutritive spheres. (After Margaret C. Ferguson). I, II, (From Bergen & Davis "Principles of Botany," by permission of Ginn & Co. Publishers). III, (From C. Stuart Gager's "Fundamentals of Botany," by permission of P. Blakiston's Son & Co. Publishers).

root. It is still imbedded in the gametophyte tissue from which it draws its nourishment.

The ovule, seed-scale, and cone, have increased in size in the meantime, the seed-scales losing their chlorophyl and becoming woody. As

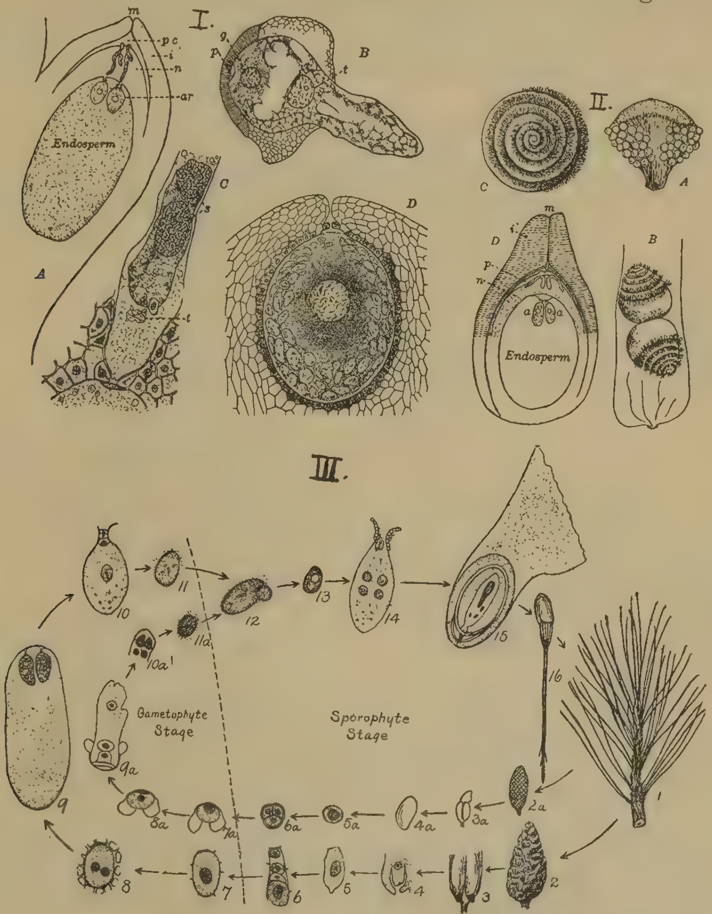


Fig. 145. I. The Gametophytes of the Pine.

A, diagram of a section of a year-old ovule; embryo sac with mature archegonia *ar* imbedded in the tissue of the *endosperm* (female gametophyte); pollen tubes (male gametophytes) growing down through the tissue of the nucellus *n*; *p c*, pollen chamber; *m*, micropyle; *i*, integument. *B*, germinating pollen grains, showing young male gametophyte; *t*, tube nucleus; *g*, generative nucleus; *p*, prothallial cell. *C*, tip of pollen tube applied to the egg; *t*, tube nucleus; *s*, the two sperm nuclei. *D*, a mature archegonium sunken in the tissue of the endosperm, showing the large egg surrounded by a jacket of cells rich in protoplasm: two neck cells of the archegonium shown just above the egg.—*B*, *C*, (After Miss Ferguson).

II. The Sperm and Ovule of a Cycad (*Zamia*).

A, lower surface of a stamen, with numerous pollen sacs in two groups. *B*, the two large top-shaped motile sperms at the end of the pollen tube ready to be discharged above the archegonia. *C*, a sperm viewed from the end, showing the spiral band which bears the cilia. *D*, diagram of a section of an ovule after pollination: *m*, micropyle; *i*, integument; *p*, pollen chamber; *n*, nucellus containing developing pollen tubes; *a*, archegonia, with large eggs imbedded in the endosperm female gametophyte).—*B*, *C*, (After Webber).

III.—Diagram of the life-cycle of a pine. (After Schaffner).

I., II., (From Bergen & Davis "Principles of Botany," by permission of Ginn & Co. Publishers).

the supply of water becomes less and less the cone becomes dry and consequently the young sporophyte stops growing. The cone and seeds are now said to be **ripe**, so that as the dry seed scales are spread out and blown away the part of the seed which contains the embryo is carried with them, and as soon as water is again supplied the embryo again begins to grow, breaking the brittle **integument** or **indusium** covering it, and the root is ready to penetrate the soil and carry water to stem and leaves of the new plant.

FLOWERS

The flowers of flowering plants (Fig. 146) consist of cone-like clusters of closed megasporophyls **(carpels)** above, and microsporophyls **(stamens)** below, subtended by a **perianth.** The plant on which the flowers grow is the **sporophyte.**

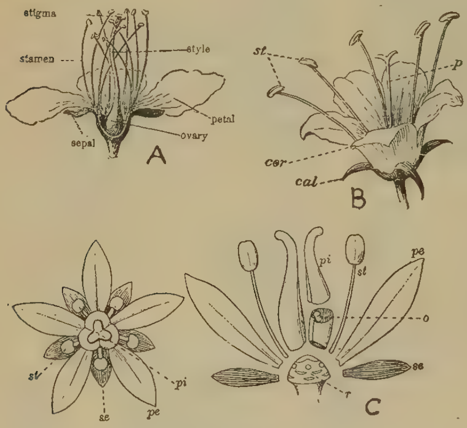


Fig. 146. Floral Organs.

A, Orange blossom. (After Bailey).

B, *Hydrophyllum*, *cal*, lobe of calyx; *cor*, lobe of corolla; *st*, stamens; *p*, pistil. (After Lindley).

C, Diagrams of flower, showing face-view and dissection. *r*, receptacle; *se*, sepal; *pe*, petal; *st*, stamen; *pi*, pistil; *o*, ovule.

The parts of a complete bisexual flower of the higher seed plants (angiosperms) are *sepals*, *petals*, *stamens*, and *pistils*. The sepals, taken together, constitute the *calyx*; the petals, taken together, constiute the *corolla*. The calyx and corolla are collectively known as the *floral envelopes*, or *perianth*.

Many angiospermous flowers consist of five circles, or whorls, two of which belong to the perianth, two to the stamens, and one to the pistils. The parts of each circle alternate in position with those of the preceding or following one, and all the members of each circle are alike. (From Bergen & Davis "Principles of Botany," by permission of Ginn & Co. Publishers).

The microspores or pollen-cells (Fig. 147) each produce a mature gametophyte which consists of a pollen tube with three nuclei (Fig. 148 B); one, the nucleus of the pollen tube itself, and the other **two sperm nuclei.**

The megaspore is retained within the ovule (Fig. 148 A), **(megasporangium).** A gametophyte with a single egg develops within the ovule. After fertilization, the zygote develops into an **embryo** and an **endosperm,** to be described shortly, while the entire ovule becomes covered with one or two coats to form the seed. With proper moisture and soil, the sporophyte escapes from the seed as with the pine. (Fig. 149.)

The purpose of a flower is the production of seed. The ripened carpel with its contained seed is known as a **fruit.** (Fig. 150.)

The Buttercup (Fig. 151) will serve as an excellent example of the flowering plants. Here we have many carpels (simple pistils) each made up of an ovary (the simple closed cavity below) which gradually tapers to a soft terminal **stigma.** The carpels are flat and open when the plant is young, but they gradually have their margins curve upwards and close. During the time the carpel is closing, an ovule grows out from the base and becomes enclosed by the carpel walls.

There are several rows of stamens encircling the pistils. Each stamen or microsporophyl bears four elongated, parallel, sporangia containing **pollen** or **microspores.** The stalk of the stamen is called the **filament,** while the four **pollen-sacs (sporangia)** are known collectively as

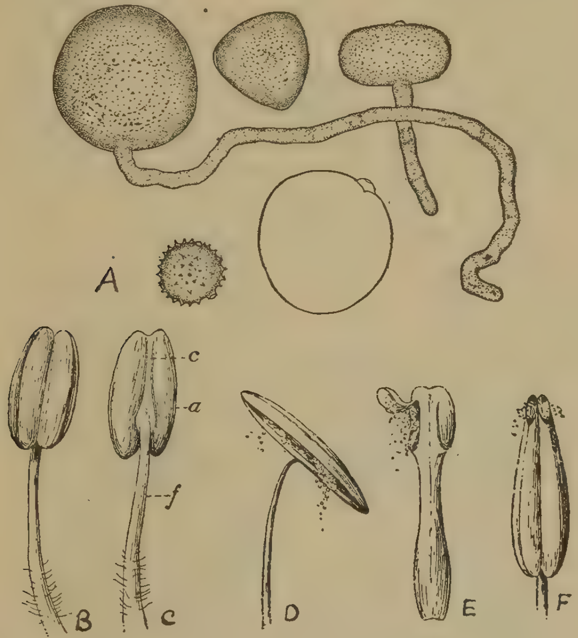


Fig. 147.

A. Different kinds of pollen grains, highly magnified, two of them forming pollen tubes. (After Duggar).

B, C. Parts of a stamen.

A, front; *B,* back; *a,* anther; *c,* connective; *f,* filament. (After Strasburger).

D, E, F, Modes of discharging pollen.

A, by longitudinal slits in the anther cells (amaryllis); *B,* by uplifting valves (barberry); *C,* by a pore at the top of each anther lobe (nightshade). (After Baillon).

the **anther.** When mature, the sporangia split longitudinally and permit the escape of the pollen.

There are two series of leaf-like structures below these we have just been discussing. These two series together form the **perianth.** The upper series is made up of yellow **petals.** The petals collectively form the **corolla.** The lower series consists of five pointed, green **sepals,** and collectively forms the **calyx.**

A **spore-mother-cell** or **archespore** arises in the ovule (Fig. 148A). This then divides into four young **megaspores,** only the deeper one developing. The other three perish. There is thus **only a single megaspore in the ovule.** The nucleus of the megaspore later divides into two, each portion moving toward opposite poles of the megaspore cavity. Each of these portions divides twice, thus forming four nuclei at each pole.

One nucleus from each pole (often called the **polar nuclei**) then moves toward the center and these two meeting, unite.

One of the nuclei about the pole functions as an egg nucleus. The two companion cells are called **synergids.** The cells at the opposite pole are called the **antipodal cells.**

It is at this time that the pollen, which has fallen on the carpel stigma, **germinates** to produce a reduced gametophyte and a pollen tube. This pollen tube penetrates the soft stigma tissues and carries two sperm toward the ovary cavity. As the pollen tube reaches the ovule it enters a tiny pore called the **micropyle** between the two integuments, and then passes through the nucellus. The ovule is thus penetrated, and one of the sperm unites with the egg and fertilizes it.

The zygote now divides continually and soon there is developed a

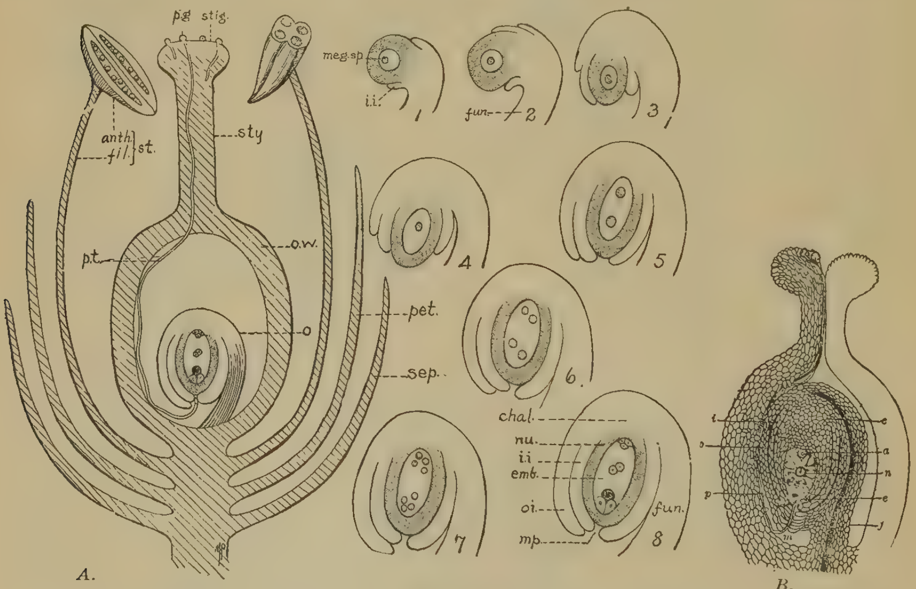


Fig. 148.

A. At the left, diagram of the anatomy of an angiospermous flower shortly after pollination; *anth.*, anther; *fil.*, filament; *st.*, stamen; *stig.*, stigma; *p. g.*, pollen grains germinating; *sty.*, style; *pt.*, pollen tube; *o. w.*, ovary wall; *o.*, ovule, containing embryo-sac; *pet.*, petal; *sep.*, sepal. 1-8, Stages in the development of the female gametophyte (embryo-sac); *meg.sp.*, megaspore-mother-cell; *i.i.*, inner integument; *o.i.*, outer integument; *fun.*, funiculus; *chal.*, chalaza; *nu.*, nucellus (megasporangium); *emb.*, embryo-sac. All diagrammatic. (From C. Stuart Gager's "Fundamentals of Botany," by permission of P. Blakiston's Son & Co. Publishers).

B. Diagrammatic Representation of Fertilization of an Ovule.

i, inner coating of megasporangium (ovule); *o*, outer coating of ovule; *p*, pollen tube proceeding from one of the pollen grains on the stigma; *c*, the place where the two coats of the ovule blend. (The kind of ovule here shown is inverted, its opening *m* being at the bottom, and the stalk *f* adhering along one side of the ovule). *a* to *e*, embryo sac, full of protoplasm; *a*, so-called antipodal cells of embryo sac; *n*, central nucleus of the embryo sac; *e*, nucleated cells, one of which, the egg cell, receives the male nucleus of the pollen tube; *f*, funiculus or stalk of ovule; *m*, micropyle or opening into the ovule.—(After Luerssen).

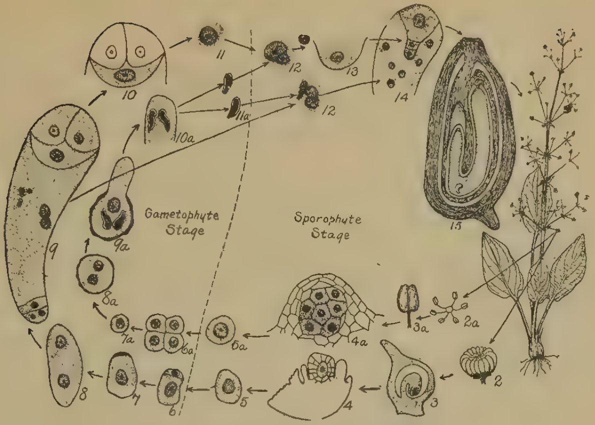


Fig. 149. Diagram of Life-cycle of an Angiosperm (*Alisma Plantagoaquatica*).

9, female gametophyte (embryo-sac); 8*a* and 9*a*, male gametophyte (pollen-grain). (After J. H. Schaffner).

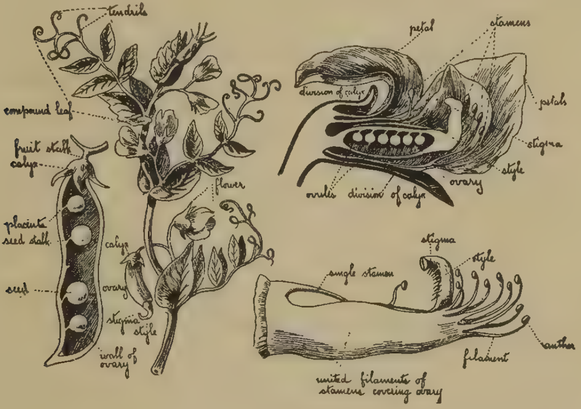


Fig. 150.

Development of the pea fruit from the pea flower. (After Yung's Chart).

tiny stem with a little root at one end and two rudimentary leaves at the other.

The gametophyte has, in the meantime, resumed its development on account of the union of the second sperm nucleus with the two polar nuclei to form the endosperm nucleus. This endosperm nucleus divides rapidly, although the cell walls are much delayed in this development. In a short time the endosperm has surrounded the embryo sporophyte and has filled in the growing ovule. This surrounding and nourishing cell mass is now called the **endosperm,** which is neither **gametophyte** nor sporophyte.

As the ovule grows in size, its outer coat becomes thickened and hardened, and the endosperm within has enlarged and solidified. A layer of cells at the base of the ovule now becomes corky and checks the supply of water, so that the whole ovule becomes hardened to form the seed.

It will be noted, therefore, that the spermatophytes also show an alternation of generations, the ordinary plant being the sexless type. It is this ordinary flowering plant which produces the microspores, or pollen grains, and megaspores. In the nuclear divisions which produce these cells, **the chromosome number is reduced to half the original number.**

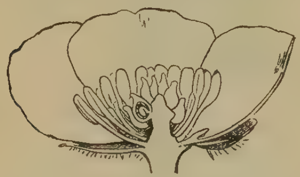


Fig. 151.
Median section of the flower of a Buttercup showing its constituent parts. On the outside (lowest down in the figure and shaded) are the sepals of the calyx: within this the large petals of the corolla of which three are shown; within this and seated higher on the axis are the numerous club-shaped stamens, each of which bears four pollen-sacs. Centrally in the flower are the numerous carpels, one of which is dissected so as to show its single ovule, or future seed. (From Bower after Le Maout and Decaisne).

The **pollen grains produce one of the sexual phases** of the life history, the male gametophyte, which forms the sperm nuclei; the megaspore **produces the other sexual phase, the female gametophyte** which bears an egg. Fertilization occurs by the fusion of a sperm cell with the egg; thus **the nucleus of the fertilized egg contains twice the number of the reduced amount of chromosomes**, one-half of which has been contributed by the sperm and one-half by the egg. The fertilized egg develops into the embryo of the seed which, **upon germination, becomes the mature sporophyte or sexless phase** of the life history with its characteristic number of chromosomes.

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CHAPTER XVII.

THE COELENTERATA

The **Coelenterata** (Gr. **koilos**=hollow+**enteron**=intestine) are all **aquatic** (mostly **marine**) animals, possessing a **single system of internal chambers** called a **gastro-vascular-cavity**, having a single opening which serves both as a mouth and a vent for egestion and excretion. In other words, **digestion and circulation all occur in this single tubular cavity.** In all the higher forms of animal life there is a **coelom** ( ), that is, a **cavity between the intestinal tract and the body wall.** This was observed in the frog where all the **viscera** ( ) are **inside the body** but **outside the intestinal tract.**

In the **Coelenterata** there is a **radial symmetry** as contradisguished from the **bilateral** symmetry of the frog.

The animals belonging to this phylum are **diploblastic,** that is, they have gone through the gastrula stage in developing and remained stationary at the end of that stage, with this exception, that they just **begin** forming a **third layer** which, however, **never becomes a regular tissue.** The **entoderm** and **ectoderm** are separated from each other by a thick mucilaginous **mesoglea** ( ) or **mesenchyme** ( ). The point of value here is that in the higher forms this **midlayer becomes an actual tissue** by forming a very definite sheet of cells called the **mesoderm,** while in the **Coelenterata** the layer does **not become cellular.** The midlayer here acts as though it were **about to form into a tripoblastic animal but has not succeeded.**

There may be a few **migratory cells** found in the mesoglea, but as a whole it is **non-cellular.**

The phylum is further distinguished by the fact that in practically all its members there are **stinging cells** [(sometimes called **nettle-cells** or **nematocysts** ( )].

Nerve cells (sensory) and **muscle cells** both **occur.**

Reproduction by non-sexual methods is the more common, though sexual methods **may alternate,** forming individuals of quite unlike appearance.

HYDRA FUSCA

The classic coelenterate for laboratory study is this little animal (Fig. 152), found in ponds and streams attached by its **basal end** to various types of aquatic vegetation. It is from 2 to 20 mm. long; consequently it can be seen by the naked eye.

The entoderm contains the **brown bodies** from which the animal receives its name. The animal itself has a **mouth** opposite the basal disk. About the mouth, there is a varying number of **tentacles,** usually four to seven. These are closed at their free ends, but their interior channels are a direct continuation of the gastro-vascular cavity.

At the **distal third** of the body, the **male gonads**, the **testes**, are seen as **cone-shaped elevations** during the breeding season (September and October), while the **female gonads**, the **ovaries**, are **knoblike projections** close to the basal disk. In addition to these sexual organs one may find **buds** on various parts of the body.

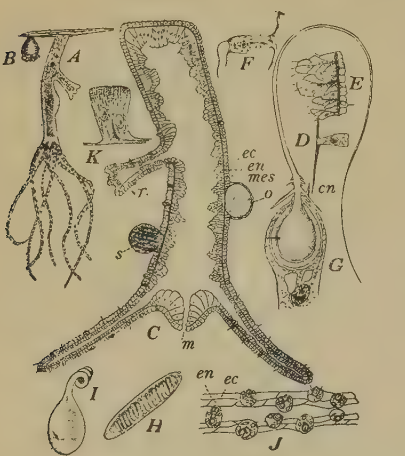


Fig. 152. *Hydra.*

A, an animal in its expanded form; *B*, the same animal contracted; *C*, a diagram of the longitudinal section of the animal, showing the internal structure; *D*, an epithelio-muscle cell; *E*, a bit of the body wall highly magnified showing the two layers of the body; *F*, a digestive cell; *G*, one of the nematocysts with its thread extruded; *H*, a second type of nematocyst with the coiled thread within the sac; *I*, nematocyst of the third type with its thread extruded; *J*, a bit of the tentacle, very highly magnified, showing the batteries of the nematocysts; *K*, two of the secreting cells of the basal disk. *cn*, cnidocil; *ec*, ectoderm; *en*, endoderm; *m*, mouth; *mes*, mesogloea; *o*, ovary; *s*, spermary; *t*, new tentacle forming. (After Conn.)

As the **Hydra** is a **diploblastic animal**, that is, one which has remained in the **gastrula stage**, it means that the simple **indentation** of the original blastula has given the animal only **epithelial** tissue, for epithelium is **surface** tissue, and both inner and outer portions of this animal are surface tissues.

The **ectoderm** is primarily **protective** and **sensory**, and is made up of two principal kinds of cells: (1) **epitheliomuscular**, and (2) **interstitial**. The former are shaped like inverted cones, and possess long (up to .38 mm.), unstriped **contractile fibrils** at their inner ends; these enable the animal to expand and contract.

The **interstitial cells** lie among the bases of the epitheliomuscular cells; they give rise to three kinds of **nematocysts** or stinging cells (Fig. 153). Nematocysts are present on all parts of the body **except the basal disc**, being most numerous on the tentacles. The interstitial cell in which the nematocyst develops is called a **cnidoblast** ( ); it contains a **nucleus** and develops a trigger-like process, the **cnidocil** ( ), at its outer end, but is almost completely filled by the pear-shaped nematocyst. Within this structure is an inverted coiled thread-like tube with barbs at the base. When the nematocyst explodes, this tube turns rapidly inside out and is able to penetrate the tissues of other animals. The explosion is probably due to internal pressure produced by osmosis, and may be brought about by various methods such as the application of a little acetic acid or methyl green. Many animals when "shot" by nematocysts are immediately paralyzed and sometimes killed by a poison called hypnotoxin which is injected into it by the tube.

Two kinds of nematocysts smaller than that just described are also found in the ectoderm of **Hydra**. One of these is cylindrical and contains a barbless thread which, when discharged, aids in the capture of prey by coiling around the spines or other structures that may be present.

Certain ectoderm cells of the basal disk of **Hydra** are **glandular** and secrete a sticky substance for the attachment of the animal.

The **entoderm,** the inner layer of cells, is primarily **digestive, absorptive,** and **secretory.** The digestive cells are large, with muscle fibrils at their base, and flagella or pseudopodia at the end which projects into the gastrovascular cavity. The flagella create currents in the gastrovascular fluid, and the pseudopodia capture solid food particles. The glandular cells are small and without muscle fibrils. Interstitial cells are found lying at the base of the other entoderm cells.

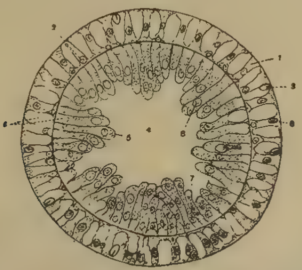


Fig. 153. Transverse Section of *Hydra fusca*. 1. Ectoderm cells (myo-epithelial). 2. Interstitial cells. 3. Nematocysts. 4. Coelenteron. 5. Endoderm cells. 6. Vacuoles. 7. Food granules. 8. Nuclei. (After Shipley and MacBride).

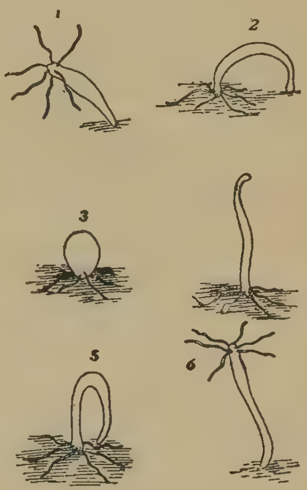


Fig. 154.
Hydra moving like a measuring worm and using tentacles as feet. (From Jennings, after Wagner).

The **mesoglea** is an extremely thin layer of jelly-like substance situated between the other two layers.

From recent investigations it seems well established that **Hydra** possesses a **nervous system,** though complicated staining methods are necessary to make it visible. In the ectoderm there is a sort of plexus of nerve-cells connected by nerve-fibers with centers in the region of the mouth and foot. Sensory cells in the surface layer of cells serve as external organs of stimulation, and are in direct continuity with fibers from the nerve cells. Some of the nerve-cells send processes to the muscle fibers of the epitheliomuscular cells, and are therefore motor in function. No processes from the nerve-cells to the nematocysts have yet been discovered, though they probably occur. The entoderm of the body also contains nerve-cells, but not so many as are present in the ectoderm.

Hydra obtains its food by throwing out **nematocysts** and paralyzing its prey. The surface of the tentacle itself is somewhat sticky which assists in keeping food from getting away, once the tentacle bends about it and carries it to the animal's mouth. After the food enters the mouth the forepart of the animal contracts to send it downward.

There are **gland-cells** in the **entoderm** which secrete a digestive fluid, and it is probable that some digestion takes place in the entoderm cells themselves. These latter have little flagella by which food is whipped about. When digestion takes place within these entoderm cells, digestion is said to be **intracellular.**

It is interesting to note that **Hydra** will not respond to food stimuli or capture prey after being fed.

The normal position of **Hydra** is an attachment to some solid object by its basal disk. When the animal moves from one attached place to another, it uses its tentacles as feet, slowly moving them along as though walking upon them, and when a suitable location has been found, releasing its body at the basal end and attaching it to the newly-found spot. (Fig. 154.)

The reproduction of **Hydra** is especially interesting in that it furnishes us with excellent proof for Weismann's insistence on the **separation** of **somato-plasm** and **germ-plasm.**

This animal usually reproduces by budding, as does yeast, except that the bud in this instance pushes out and becomes **stalk-shaped.** The tentacles of the bud grow from the distal end of the new stalk bud, and the entire new organism is pinched off from the mother stalk or body. (Fig. 152, C.)

In fact, it is not uncommon for one of these buds to form new buds on its body before it is ready for an independent existence itself. At all times, the cavity of the newly forming animal is in **direct continuation** with the mother cavity, until the pinching-off process occurs.

There is a division of the body sometimes, though very infrequently, by **simple fission** ( ), that is, by a splitting of the entire animal **lengthwise,** commencing from the distal end and extending to the basal disk. Sometimes, also, even the buds reproduce in this manner, while transverse fission is not unknown.

In the **sexual method,** the spermatozoa from the testes escape into the surrounding water. The **eggs arise** in the ovary **from ectodermal interstitial cells.** There is usually only one egg in the ovary that grows to maturity, though several may begin growth, only to have one of them —**the stronger by virtue of position, or ability to obtain more food**— absorbing the others. Two **polar bodies** are given off from this egg when it is ready for fertilization and then it is said to be **mature.**

The **cleavage** of the egg **is total,** and **almost equal.** After this original egg has divided several times the blastula is formed with a cavity called the **blastocoel** ( ). Cells from the inner portion **bud off** and make a sort of **solid gastrula-like structure**; this later becomes the **entoderm.** The "Ectoderm now **secretes a thick chitinous** ( ) **shell** covered with sharp projections. The embryo then separates from its parent and falls to the bottom, where it remains unchanged for several weeks. Then **interstitial cells** make their appearance. A subsequent resting period is followed by the breaking away of the outer chitinous envelope, and the elongation of the escaped **embryo. Mesoglea** is now secreted by the ectoderm and entoderm cells; a circlet of tentacles arises at one end, and a mouth appears in their midst. The young **Hydra** thus formed soon grows into the adult condition." Almost any part of the **Hydra** may be cut off and **each part will grow into a complete new animal.** This is supposed to be due to the fact that **Hydra** is an animal composed of **tissues** which have **not yet become organs** as in the higher animals. Therefore **the original germ-cells have not divided as often** as in higher animals, and **each cell contains a little portion of germ-plasm,** which causes each cell to have **the power or potentiality of producing a complete organism.** This theory receives additional weight from the fact that the **Hydra** can and **does reproduce in practically every known way, sexual, asexual,** by **budding,** by **longitudinal** and **transverse fission,** in addition to having the ability of restoring any lost part, and of forming a complete new animal from the smallest part.

When, however, an animal is classified in one of the higher phyla and its somatoplasm is therefore further removed from the germplasm, the regenerative ability decreases. This is shown in man, where a piece of skin will grow again when removed, though an entire finger will not be replaced.

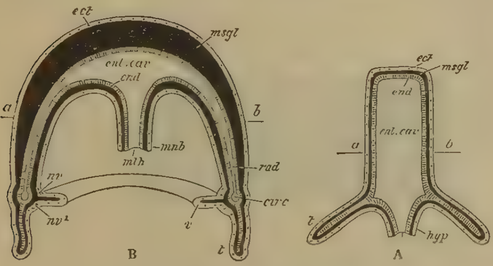


Fig. 155. Medusa, showing gastrula-form.

Diagrams showing the similarities of a polyp (*A*) and a medusa (*B*). *circ*, circular canal; *ect*, ectoderm; *end*, entoderm; *ent. cav*, gastrovascular cavity; *hyp*, hypostome; *mnb*, manubrium; *msgl*, mesoglea; *mth*, mouth; *nv*, nerve rings; *rad*, radial canal; *v*, velum. (From Parker and Haswell).

Regeneration means that a part of an organism can reproduce the whole or at least a portion of the lost part. This is distinguished from **reproduction,** though in **Hydra** the two are intimately related.

As has been stated, there is an **alternation of generations** in this animal. The **form** we have been discussing so far is called the **Hydroid form or the polyp** ( ); while the **asexual** form, so different in appearance from the hydroid, **is umbrella shaped** and called a **medusa** ( ), (Fig. 155.) The convex portion is usually the upper surface, and tentacles hang down from the edges. At first glance the two forms appear totally dissimilar, but with a clear conception of what a gastula really is, we can readily imagine grasping the hydroid form by the mouth and pushing this portion of the animal in upon itself, when we have the **gastrula still,** and **also the medusoid form.**

It must be remembered that some species may **always** retain the medusoid form and others the hydroid, while still a third may **alternate regularly or irregularly** between the two.

Obelia (   )

This is a **colonial** form of **Hydra** found attached to rocks, wharves, and to various algae, in which budding began, but the newly-formed animals remained attached to the parent stalks. (Fig. 156.)

Such a colony consists of a basal stem, the **hydrorhiza** (   ), which is attached to the substratum. At intervals, upright branches known as **hydrocauli** (   ) are given off. At every bend in the hydrocaulus a branch arises. The stem of this side-branch is ringed and expanded at the end into a hydra-like structure, the **hydranth** (   ). Each **individual polyp** consists of a hydranth and the part of the stalk between the hydranth and the point of origin of the preceding branch. Full-grown colonies usually bear reproductive members **(gonangia)** in the angles where the hydranths arise from the hydrocaulus.

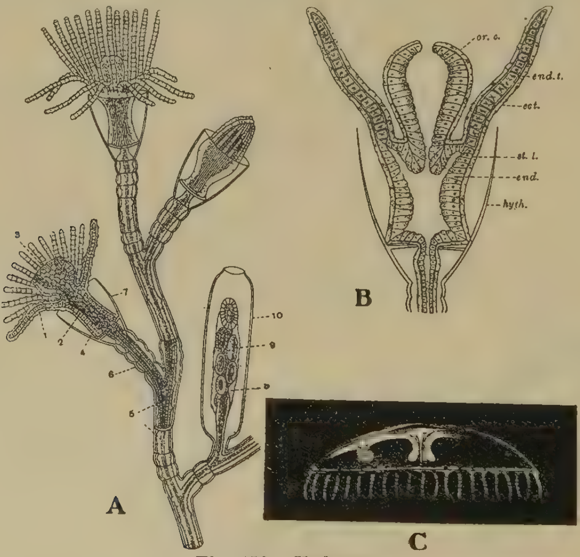


Fig. 156. *Hydrozoa.*
A, part of a colonial Hydrozoan, *Obelia*. *B*, Longitudinal section through a single hydranth. *C*, Cross section through medusoid individual. 1, ectoderm; 2, entoderm; 3, mouth; 4, coelenteron; 5, coenosarc; 6, perisarc; 7, hydrotheca; 8, blastostyle; 9, medusa-bud; 10, gonotheca; *or.c*, mouth region; *end.* and *endt.*, entoderm; *ect.*, ectoderm; *st.l.*, mesoglea lying between ectoderm and entoderm; *hyth*, hydrotheca. (From Borradaile after various authors).

All of the soft parts of the **Obelia** colony are protected by a chitinous covering called the **perisarc** (   ) which is ringed at various places, and is expanded into **gonothecae** and cup-shaped **hydrothecae** (   ) to accommodate the hydranths.

A shell extends across the base of the hydrotheca which serves to support the hydranth. The soft parts of the hydrocaulus and of the stalks of the hydranths constitute the **coenosarc** (   ) and are attached to the perisarc by minute projections. The coenosarcal cavities of the hydrocaulus open into those of the branches and thence into the hydranths, producing in this way a common **gastro-vascular cavity.**

The coenosarc consists of two layers of cells—an outer layer, the **ectoderm,** and an inner layer, the **entoderm.** These layers are continued into the hydranth. The **mouth** is situated in the center of the large knob-like **hypostome** (   ) and the **tentacles** (   ), about thirty in number, are arranged around the base of the hypostome in a single circle. Each tentacle is solid and consists of an outer layer of ectodermal cells and a single axial row of entodermal cells with a large number of **nematocysts** at the extremity. The hydranth captures, ingests, and digests food just as does **Hydra.**

The **reproductive organs** develop quite like the hydranths, as buds from the hydrocaulus. They thus represent modified hydranths. The central axis of each is called a **blastostyle** (   ), and together with the gonothecal covering, is known as the **gonangium** (   ). The blastostyle gives rise to **medusa-buds** which soon become detached and pass out of the gonotheca through the opening in the distal end.

Some **medusae** produce eggs, and others, sperm. The fertilized eggs again develop into colonies like those which gave rise to the medusae. The medusae provide for the dispersal of the species, since they swim about in the water and establish colonies in new habitats. The medusae of **Obelia** are shaped like an umbrella with a **fringe of tentacles** and a number of **organs of equilibrium** on the edge. Hanging down from the center is the **manubrium** (   ), with the mouth at the end. The gastrovascular cavity extends out from the cavity of the manubrium into four **radial canals** on which are situated the reproductive organs.

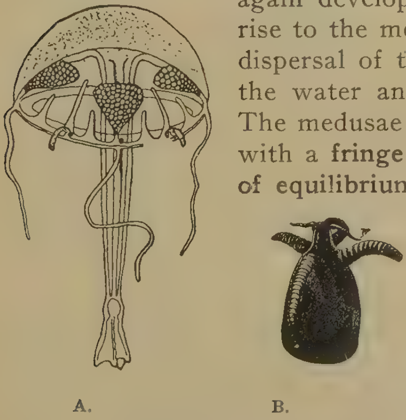


Fig. 157.

A. Liriope Exigua (family *Geryoniidae*). (Mayer).

B. Hydralike stage in the development of *Gonionemus.* One of the tentacles is carrying a worm (*w*) to the mouth. Tentacles in contracted state. (From the Cambridge Natural History, after Perkins).

"The **germ-cells** of the medusae of **Obelia** arise in the ectoderm of the manubrium, and then migrate along the radial canals to the reproductive organs. When mature, they break out into the water. The eggs are **fertilized** by spermatozoa which have escaped from other medusae. Cleavage is similar to that of **Hydra**, and a hollow **blastula** and solid **gastrula-like** structure are formed. The gastrula-like structure soon becomes ciliated and elongates into a free-swimming larva called a **planula** ( ). This soon acquires a central cavity, becomes fixed to some object, and proceeds to found a new colony."

When there is an alternation of generations, the one being sexual, reproducing by eggs and spermatozoa, and the other asexual, reproducing by division or budding, such as alternation of generations, is called **metagenesis** ( ).

In **Obelia** the asexual generation (the colony of polyps) forms buds of two kinds, the **hydranths** and the **gonangia** ( ). The sexual generation (the medusoid) reproduces only by eggs and spermatozoa.

Hydra do not have a regular medusoid stage and **Geryonia** (Fig. 157A), ( ), no polyp or hydroid stage.

Gonionemus (Fig. 157B), ( )

The structure of a medusa or hydrozoan jellyfish is well illustrated by **Gonionemus,** which is quite common along the eastern coast of the United States. It is about half an inch in diameter. In general form it is similar to the medusa of **Obelia.** The convex or **aboral** surface is called the **exumbrella** ( ), and the concave, or oral surface, the **subumbrella** ( ). The subumbrella is partly closed by a perforated membrane called the **velum** ( ). The animal takes in water into the subumbrella-cavity, and then forces it out through the central opening in the velum by the contracting of its body, thus propelling the animal in the opposite direction. This method of locomotion is called **hydraulic.** It is common to all medusae.

The **tentacles** (from sixteen to about eighty) are capable of great contraction. Adhesive or **suctorial pads** are found near their tips. Hanging down into the subumbrellar cavity is the **manubrium** with the mouth at its end surrounded by four frilled oral lobes. The mouth opens into a **gastrovascular cavity** which consists of a central "stomach" and four **radial canals.** The radial canals enter a **circumferential canal** which lies near the margin of the umbrella.

The cellular structure of **Gonionemus** is similar to that of **Hydra,** but the mesoglea is thicker which gives the animal a jelly-like consistency. Then there are many nerve cells scattered about beneath the ectoderm, and a nerve ring is placed about the velum and there are **sensory cells** with a **tactile function** on the tentacles. At the margin of the umbrella there are two kinds of sense organs: (1) Those at the base of the tentacles are round bodies which contain pigmented entoderm cells and communicate with the circumferential canal; (2) those between the bases of the tentacles, which are small outgrowths, probably organs of equilibrium, that is, **statocysts** ( ). **Muscle fibers,** in both exumbrella and subumbrella, are present.

Beneath the radial canals the sinuously folded **reproductive organs or gonads,** are suspended. **Gonionemus is dioecious** ( ). each individual producing either eggs or spermatozoa. These reproductive cells break out directly into the water, where **fertilization** takes place. A ciliated **planula** develops from the egg as in **Obelia.** This soon becomes fixed to some object, and a mouth appears at the unattached end. Then four tentacles grow out around the mouth and the **Hydra-like larva** is able to feed. Other similar **Hydra-like** larvae bud from its walls. How the medusae arise from these larvae is not known, but probably there is a direct change from the hydroid form to the medusa.

POLYMORPHISM

Whenever there is a division of labor among the different members of the same colony so that each does a particular work, such colony is said to be **polymorphic** ( ) if there are more than two kinds of specialized individuals; **dimorphic** if only two different specializations have taken place.

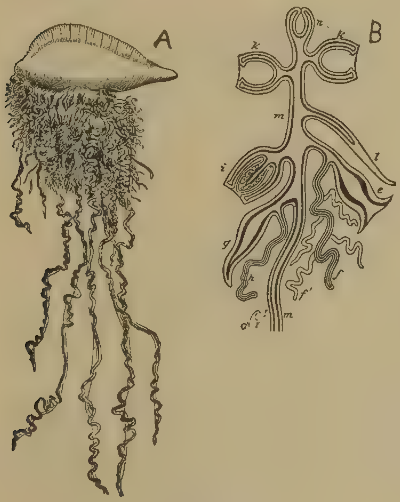


Fig. 158.

A, *Physalia* or Portuguese man-of-war, a colonial *Hydrozoon.* (From Hegner, after Agassiz).

B, Diagram showing possible modifications of medusoids and hydroids of a hydrozoan colony of the order *Siphonophora. c.* gastrozooid with branched, grappling tentacle, *f*; *g*, dactylozooid with attached tentacle, *h*; *i*, generative medusoid; *k*, nectophores (swimming bells); *l*, hydrophyllium (covering piece); *m*, stem or corm; *n*, pneumatophore. The thick black line represents entoderm, the thinner line ectoderm. (From Hegner after Allman).

The **"Portuguese man-of-war"** (Fig. 158) is an excellent example of the former, in that it is a bladder-like structure to which many tentacles are attached. It floats upon the water. Some of these tentacles are **nutritive,** others are **tactile** ( ); some contain **batteries of nematocysts,** others are **male reproductive zooids,** and still others give rise to **egg-producing medusae.**

The **Coelenterata** (together with the **Echinoderma)** were formerly called **Radiata** on account of their radial form. It is now known that in the higher groups of coelenterates this radial form may be transformed into a biradial or bilateral symmetry.

Older writers often spoke of the coelenterates as **Zoophyta** (animal-plants) on account of their resemblance to plants both in appearance and in their method of attachment. Then, too, these animals simulate

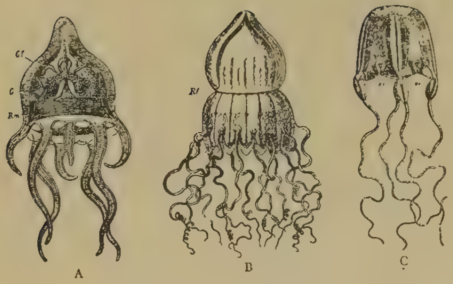


Fig. 159. *Scyphozoa.*

A, Tessera princeps, order Stauromedusae. *B, Periphylla hyacinthia,* order Peromedusae. *C, Charybdea marsupialis,* order Cubomedusae. *G,* gonads; *Gf,* gastral filaments; *ov,* gonads; *Rf,* annular groove; *Rk,* marginal bodies; *Rm,* circular muscle; *T.* tentacles. (From Sedgwick, after Haeckel.)

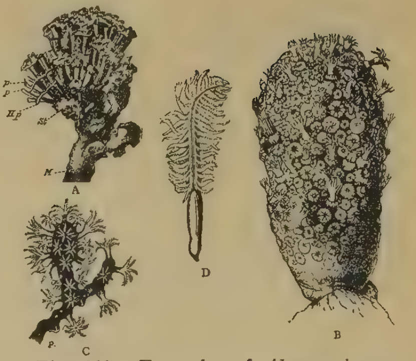


Fig. 160. Examples of *Alcyonoria.*

Coral. *A, Tubipora musica,* organ-pipe coral, a young colony. *Hp,* connecting horizontal platforms; *p,* skeletal tubes of the zooids; *St,* the basal stolon. *B, Alcyonium digitatum,* with some zooids expanded. *C, Corallium,* a branch of precious coral. *P,* polyp. *D, Pennatula sulcata,* a sea-feather. (A and B, from Cambridge Natural History; C, from Sedgwick, after Lacaze Duthiers; D, from Sedgwick, after Kölliker).

plant-conditions by their method of reproduction, namely, by fission and budding, as well as often forming colonies.

CLASSIFICATION

There are three great classes of coelenterates — **Hydrozoa** ( ), **Scyphozoa** ( ), and **Anthozoa** ( ).

The **Hydrozoa** possess neither stomodaeum nor mesenteries ( ), and their sex-cells are discharged directly to the exterior. **Hydra** and **Obelia** belong to this class.

The **Scyphozoa** may, or may not, possess a stomodaeum and mesenteries. The stomodaeum is more or less equivalent to the gullet in coelenterates, serving as the passageway between mouth and the gastro-vascular cavity or "stomach." The membranes which hold this stomodaeum in place are called **mesenteries.**

The position of tentacles and tentaculocysts is made use of in separating the coelenterates into the various classes.

Examples of Scyphozoa (Fig. 159) are: **Tessera,** order **Stauromedusae**; **Periphylla,** order **Peromedusae**; and **Charybdea,** order **Cubomedusae.**

The **Anthozoa** are divided into two sub-classes as follows: **Subclass I. Alcyonaria** (Fig. 160), all of which have eight hollow, pinnate, tentacles and eight complete mesenteries. They also possess one **siphonoglyphe,** which is ventral in position, while all the retractor muscles of the mesenteries lie on the side toward the siphonoglyphe ( ).

Examples of an **Alcyonaria** are the organ-pipe coral known as **Tubipora** of the order **Stolonifera,** and the pretty sea-fans and the red coral

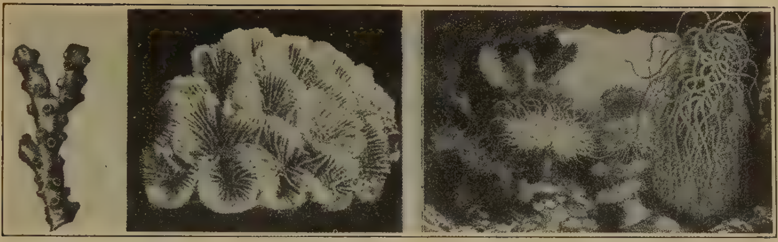


Fig. 161. Examples of *Zoantharia*.
A, *Oculina speciosa*, a branch of madreporarian coral. (After Sedgwick).
B, *Meandrina*, a rose-coral of the order Madreporaria. (After Weysse).
C, A group of sea anemones. (After Andres).

used in jewelry. The latter is known as **Corallium** of the order Gorgonacea.

Sub-class II. Zoantharia (Fig. 161). These usually possess many simple, hollow tentacles, generally arranged in multiples of five or six. There are two siphonoglyphes as a rule, and the mesenteries vary in number. The retractor muscles are never arranged as in the **Alcyonaria.** A skeleton may or may not be present. The animals may be simple or colonial.

Examples of **Zoantharia** are the sea-anemones such as **Actiniaria,** and the stony corals such as **Oculina** of the order **Madreporaria,** and the rose-coral **Meandrina,** order **Madreporaria.**

CHAPTER XVIII.

INTRODUCTION TO THE COELOMATA

From what has already been learned it is known that animals may be divided, according to whether or not they have a backbone, into two great groups—the **vertebrates** and the **invertebrates.** **Also**, according to whether they are composed of one or more cells into **protozoa** and **metazoa,** and the latter according to the number of germ layers each form develops, into **diploblastic** and **triploblastic** organisms.

Now we come to another common method of classifying them into two groups—the **coelomata** and the **acoelomata.**

With the exception of the frog, all of the animals studied so far—the protozoa and coelenterata—belong to the **acoelomata,** because they have no additional cavity between the digestive tract and the body wall. **Coelomata have such a body-cavity.** All animals higher in the scale of life than hydra are coelomates.

It will be remembered that in hydra there was a thick mucilaginous substance—the mesoglea—formed between the ectoderm and entoderm. In some of the lower forms of acoelomata there are processes stretching across from inner to outer germ-layer, which often secrete fibers which become "connective tissue or may be developed into muscular fibers. Where the cells and fibers are sparse, this space is said to be a **primary body-cavity.** Where they are abundant, it is called **parenchyma** (   ) or **connective tissue.**"

This body cavity, also known as the **coelomic cavity** (Fig. 162) or **coelom** (Gr. **koiloma**=a thing hollowed out), consists of "one or more pairs of sacs with perfectly defined walls lying at the sides of the entodermic tube. In the adult these sacs join each other above and below the entoderm, and the adjacent walls entirely or partly break down, and thus one continuous cavity results. The **wall of the coelom** and **the tissues derived from it are** known as **mesoderm.**"

The distinctive difference between the primary body cavity of the coelenterates and this secondary body-cavity of the coelomates, is a **difference in the walls** of the cavities and **not in the space** between the walls. The outer wall of the primary body cavity is merely ectoderm.

It will be remembered that this primary body cavity serves both as a digestive and circulatory system in the coelenterates. In the higher animals, therefore, it may be said that the blood-vessels are really part of the primary body cavity.

In triploblastic animals the **mesoderm** does not form a completely solid mass extending the entire length of the body. A slight cavity is left in its center extending along the long axis of the organism.

This mesoderm forms in two ways (1) either by little pouches growing from the entoderm which are then nipped off, or (2) by two large cells which grow as buds from the entoderm, which once formed, grow rapidly, forming the so-called **mesodermic bands,** which bands later become hollowed out. The two cells forming the original bud are termed **pole-cells. This hollowed out portion is the coelom.** A close study of Figure 163 will make a better understanding of the above possible.

It must be understood that these two forms are not likely to be found in any one animal.

The open space thus formed which we have called the coelom has thus a **layer toward the outside of the body** and a layer of cells or **wall toward the entoderm** from which it sprang. The outer wall of the coelom is called the **somatic layer** or the **somatopleure** ( ), while the inner is known as the **splanchnopleure** ( ).

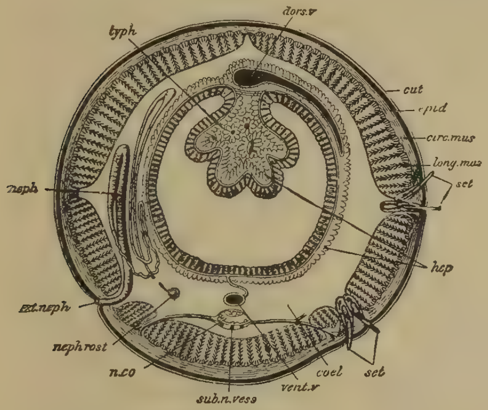


Fig. 162.

Transverse section through the middle region of the body of the earthworm, *Lumbricus, circ.mus,* circular muscle fibers; *coel,* coelom; *dors.v,* dorsal vessel; *epid,* epidermis; *ext.neph,* nephridopore; *hep,* chlorogogen cells; *long.mus,* longitudinal muscles; *neph,* nephridium; *nephrost,* nephrostome; *n.co,* nerve-cord; *set,* setae; *sub.n.vess,* subneural vessel; *typh,* typhlosole; *vent.v,* ventral vessel. (From Parker and Haswell, after Marshall and Hurst).

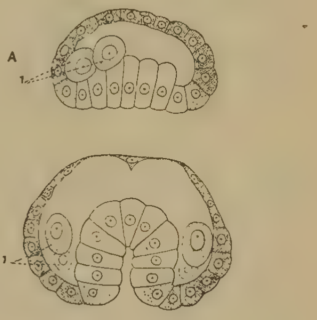


Fig. 163.

Two stages in the early development of a common fresh-water mollusc, *Planorbis,* to show the origin of the mesoderm cells.

The ectoderm cells are deeply shaded, the endoderm cells are unshaded. *A.* Young stage in which the endoderm has not begun to be invaginated; it is a lateral optical section. *B.* Older stage, optical section seen in front view; the endoderm cells are invaginating, and the two mesoderm cells are seen on each side. 1. Mesoderm or pole-cells; in B, each has budded off another mesoderm cell. (After Rabl).

When pole-cells form, the cavity of the digestive canal is small in proportion to the thickness of its wall, so that the pole-cell may be considered as "a solid pouch."

In most Coelomata the mesoderm or coelomic wall forms by far the greatest portion of the body. There are sometimes cells which form in the primary body-cavity, to which some writers have also applied the term mesoderm. **This term should, however, be reserved for the walls of the coelom as just described, while mesenchyme** ( ) should be used for the cells forming within the primary body-cavity.

Mesenchyme arises from different germ-layers in different phyla of animals. It may arise from the entoderm or ectoderm or both, or even from the walls of the coelom. In this latter case it may spring from ectoderm, entoderm, and mesoderm. In the higher coelomata it arises, however, "partly from the ectoderm but principally from the outer wall of the coelom. **Everywhere it gives rise to connective tissue** and to the tissues developed from this (tendon, cartilage, bone, etc.), whereas the **coelomic wall** or **true mesoderm gives rise to the generative cells and their ducts, and the main parts of the muscular system,** including the muscular coats of the principal blood-vessels.

The **entoderm,** after the mesoderm has separated from it, **forms the lining of the digestive tube and of its appendages,** which in the higher Vertebrata are the organs known as **lungs, liver, pancreas,** and **urinary bladder.** The basis of the skeleton of Vertebrata, the gelatinous rod called the **notochord, also arises from the entoderm.**

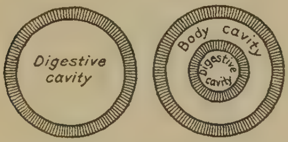


Fig. 164.
Diagrammatic cross section of the body of a coelenterate (such as the hydra) and of a coelomate. The latter forms a tube within a tube.

After gastrulation has taken place in the growing embryo, there are only two germ layers, ectoderm and entoderm. The inner layer undergoes various changes, as it is to be used for a totally different purpose from its outer protective layer. It must be remembered, however, that just after indentation, both layers are alike in that they have both constituted the simple blastula. The blastula, it will be remembered, is but a single layer of cells forming a more or less spherical body. The opening formed by gastrulation and known as the mouth or **stomodeum** ( ) does not undergo the same change that does the part on the more interior portion of what is now called the entoderm. In fact, the **mouth region remains ectodermal.** As soon as an organism has formed three germ-layers and has both an opening in its body for ingestion as well as egestion of food, there comes another infolding of ectoderm in the gastrula at the opposite end from the stomodeum. This forms an anal opening which is called a **proctodeum** ( ). This infolding, just as the stomodeal infolding, is also ectoderm.

It is of interest and value here to know that the **entire brain and nervous system arise from ectoderm.** It will be readily understood why this is so, when it is realized that no organism from the simplest flower up to man, could possibly live unless there were some method by which such organism could protect itself when danger threatened. Any mechanical injury, such as pressure or laceration, cannot affect the body unless it strikes the outer portions first. Therefore the **sensory nerve endings must be placed close to the outer portion** of the body so that they will receive the message of threatened danger first. These danger messages are then carried to the **central nervous system** where a **co-ordination** must be brought about between the sensory fibers and the motor nerves, thus making it possible for any or all parts of the body to be withdrawn from the zone of danger.

For **toxic injuries,** as well as **parasitical invasions,** which come through the intestinal tract, the student must think of the body, when drawn out completely, as forming a tube within a tube. (Fig. 164.)

The inner one called the intestinal, or digestive tract, has an opening straight through the body. This means that the inside of the digestive tract is really **outside the body in so far as** exterior environmental conditions may affect it, such as temperature, air, etc. In other words, it is as though one took an ordinary small gas or water pipe and placed it in water. There would be the same kind and quality of water on the inside as there would be on the outside of the pipe.

The larger outer tube is the outer body wall.

"The internal anatomy of the lower animals was first studied by physicians and others primarily interested in human anatomy. An unfortunate consequence is that a large number of names are used in the description of simpler animals which are based on fanciful resemblances between their organs and those of man. As a consequence many of these names are quite misleading. To give some instances: The word stomach in the Lobster denotes part of the stomodaeum, in the vertebrata it signifies part of the entodermic tube. The pharynx ( ) of an earthworm is the stomodeum, in a fish it includes both stomodeum and the first part of the entodermic tube. The term liver has also been much abused.

"The names taken from the higher animals, which are customarily used in the description of the alimentary canal, are as follows: Mouth or **buccal-cavity, pharynx, oesophagus, stomach** or **crop, gizzard, intestine,** and **rectum.** They are applied generally to parts of it succeeding one another in the order above given. The significance of these will be explained in each case: it would perhaps be more logical to sweep away altogether these and a host of similar terms employed to designate other parts of the body, but so deeply are they engrained in zoological literature that such a course would render unintelligible most anatomical descriptions of species that we possess."

CHAPTER XIX.

THE EARTHWORM

Earthworms are found in practically all parts of the country, living in burrows not lower than 12 or 18 inches beneath the earth's surface. It is in about these depths that they find the richest portions of decaying vegetable and animal substances upon which they feed. Professor Latter has given us a most interesting account of these animals. During "periods of prolonged drought or frost they descend to greater depths and undergo **aestivation** (   ) or hibernation (   ), as the case may be, coiled up into a compact spiral and lying in a small excavated chamber. This is lined with small stones which prevent close contact with the surrounding earth and so permit free respiration. The sides of the burrow are kept moist by slime discharged from the glandular cells of the skin, and perhaps by liquid discharged from the body-cavity through the dorsal pores which occur in the grooves that separate segment from segment. The slime is said to possess antiseptic properties, and thus preserve the skin of the worm from harmful bacteria.

"The mouth of the burrow is guarded by small stones or more frequently by one or more leaves pulled in to a greater or less distance. Fir-needles, stalks of horse-chestnut leaves and other similar things are often to be seen standing nearly erect upon the ground, their lower ends having been forcibly dragged into the mouth of a burrow by a worm. On still, warm nights in early autumn the rustling noise of fallen leaves being dragged along by worms is often plainly audible in favorable localities. Darwin has pointed out that worms exhibit considerable intelligence in drawing the narrow end of leaves of various shapes foremost into the burrow: the leaves with broad bases and narrow apices are generally pulled in tip first, whereas when the base is narrower than the apex the reverse position is usually found. There is no doubt that worms can judge which end of any leaf is the better to seize. The reason for thus pulling objects into the entrance of the burrow is probably to prevent the entry of foes, centipedes, parasitic flies, etc., to keep the burrow moist by preventing evaporation, to keep out the cold lower strata of air at night, to bring food supplies within safe reach, and also to enable the worms to lie near the mouth of the burrow unobserved. Here, however, they are not secure from all attack, for the quick ears of the thrush and other birds enable them to detect the slightest movement and, with a quick plunge of the beak, to seize, and after a brief tug-of-war, to extract the worm from its refuge. Frequently the well-known worm-castings are thrown up on the surface, and when this is so, leaves are not, as a rule, drawn into the burrows, the heap of castings serving the purpose.

"The burrow is made partly by the awl-like, tapering anterior end pushing aside the earth on all sides, and partly by the actual swallowing of the earth as the worm advances, so that the animal literally eats its way into the soil. The organic material in the swallowed soil serves as food, and the residue in a state of very fine division passes out at the anus, and is used either to form the above mentioned castings or as a lining to the burrow, especially where this passes through hard, coarse earth.

"Perfectly healthy worms seldom leave their burrows completely except perhaps after a very heavy rain. The majority of those so frequently found traveling over the surface of roads and paths after rain are infected by the larvae of parasitic flies and doomed to die. On warm, moist evenings, however, worms may be seen in hundreds lying stretched on the surface of the ground with only the broad flattened posterior end remaining in the burrow. Here we see one of the uses of this modification in the shape of the hinder segments of the body: their greater width enables them to obtain a firm purchase on both sides of the burrow, and thus the worm is provided with a sure anchor on which it can pull, and at the slightest alarm, shoot back like stretched elastic into the security of its burrow. At other times the flat tail is employed trowelwise in smoothing the excrement against the walls of the burrow or in disposing the castings on this side and on that of the mouth of the burrow."

"The effects produced on the surface soil by the action of earthworms have been fully pointed out by Charles Darwin in his well-known book, 'Vegetable Mould and Earthworms.' It will be sufficient here to call attention to a few facts only. Worms play a most important part in maintaining the soil in a state suitable to vegetation. The burrows form ventilating tubes whereby the soil is aerated and respiration by the roots of plants rendered possible; at the same time they open up drainage channels, preventing the surface from becoming waterlogged. Doubtless also roots find an easy passage through the soil along the lines of burrows even after the walls have more or less fallen in. Moreover, the excrementitious earth with which the burrows are lined is peculiarly suited to root fibers, being moist, loose and fertile. Microscopic examination of the earth deposited by worms shows it to resemble two-year-old leaf mould such as gardeners use for seed-pans and pricking-out young seedlings; most of the plant-cells are destroyed, shreds and fragments alone remaining, discolored and friable, mingled with sand grains and brown organic particles. In chemical composition, too, worm-castings are very similar to fertile humus.

"The castings which are thrown up on the surface materially improve the quality of the upper soil, and render it more fit for the germination of seeds, many of which directly or indirectly get covered by the upturned earth. It has been reckoned that there are upwards of 50,000 worms in an acre of soil of average quality: hence the total effect of the work of this vast host must be very considerable. Each worm ejects annually about 20 ozs. of earth. The weights of earth thrown up in a single year on two separate square yards observed by Darwin were respectively 6.75 and 8.387 lbs., amounts which represent respectively 14.58 tons and 18.12 tons per acre per annum.

"In addition to this tilling action worms improve the quality of the soil by the leaves and other organic **debris** which they drag into their burrows, and thus bring within reach of bacteria. These, as it is well known, especially abound in the upper soil, and effect the speedy decomposition of dead animals and vegetable tissues.

"Archaeologists are indebted to worms for the preservation of many ancient objects, such as coins, implements, ornaments, and even the floors and remains of ancient buildings that have become buried by the soil thrown up as worm-castings. The process of disappearance is of course hastened by the excavations effected by the worms below the surface, for the collapse of the burrows slowly but surely allows objects on the surface to sink downwards.

"In the disintegration of rocks, and the denudation of the land, worms play an important part. The penetration of the burrows, and the lining with castings, carries down the humus-acids to a considerable depth and exposes the underlying rocks to their solvent action. Within the body of the worm itself small stones and grains of sand are reduced to yet finer dimensions and rendered the more easy to transport by wind and water. On sloping surfaces the upturned castings, at first semi-fluid, flow down, and when dry roll down the incline, or are washed by the rain into the valleys and ultimately carried out to sea, while on level ground the dried castings are blown away to lower spots by the wind. The more or less parallel ridges that are frequently found on the sloping sides of grass-clad hills are in part, at any rate, formed by the material derived from worm-castings, which has temporarily lodged against tufts of grass, etc., and in turn furnishes a richer and deeper soil for stronger growth which arrests yet more and so increases the ledge. All land surfaces, whether level or sloping, provided they are occupied by worms, are reduced in altitude by their action. In no small degree, then, may earthworms be held responsible for our valleys and hills and all the softer features of our scenery."

EXTERNAL APPEARANCE

There are rings or **segments** (Fig. 165) extending along the entire length of the animal's body formed by constrictions or **annuli.** The segments themselves are known as **somites** or **metameres.** It is from these ring-like (L. **Annulus**-ring) constrictions and segments that the animals belonging to this group are named **Annelids** or **Annulata.** Worms are divided into annelids, or segmented worms, **plathyhelminthes** or **flat** worms—(Gr. **platy**=flat+**helminthes**=worms); and **nemathelminthes** or **thread-worms** (Gr. **nema**=thread+**helminthes**=worms).

The important external characteristic in the annelids is, then, a **regional** differentiation. That is, the forming of separate segments or regions externally, and a separation and segmentation of many internal structures. Metamerism is common in all higher forms of organisms except the soft-bodied animals such as the **Molluscs** and the spiny-skinned **Echinoderms**. In Man this metamerism is distinctly shown in the separate segments of the spinal column.

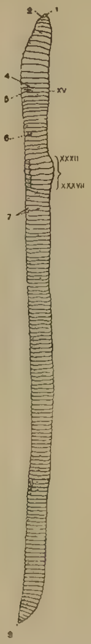


Fig. 165.

Latero-ventral view of *Lumbricus terrestris*, slightly smaller than life-size. (From Hatschek and Cori).

1. Prostomium. 2. Mouth. 3. Anus. 4. Opening of oviduct. 5. Opening of vas deferens. 6. Genital chaetae. 7. Lateral and ventral pairs of chaetae.

XV, XXXII, and XXXVII are the 15th, 32nd, and 37th segments. The 32nd to the 37th form the clitellum. (After Latter).

There are many differentiations in various regions of the earthworm's body. For example, the anterior end is sensitive to touch and light to a much greater degree than the middle and posterior portions. On the eighth, ninth, fourteenth and fifteenth segments there are openings of the reproductive system, while from the twenty-eighth to the thirty-seventh segments a broad band surrounds the dorsal and lateral portions of the worm called a **clitellum**, the function of which will be explained under Reproduction.

There are from 140 to 180 segments in the earthworm. All of the differentiation just mentioned occurs toward the anterior end of the worm. We therefore say the earthworm has an **anterior-posterior differentiation**.

As the earthworm will always place itself in a definite position when crawling along—that is, will "right" itself if it be turned about, we speak of that portion toward the surface on which it moves as the **ventral surface** and the surface away from this as the **dorsal**. If an animal thus rights itself there must be a difference between the ventral and dorsal surfaces. This difference is spoken of as a **dorso-ventral differentiation** or **dorsiventrality**.

The ventral surface will be found to be more flattened than the dorsal, while many little whitish glands are present toward the anterior end. On the ventral surface are also found the mouth, anus, reproductive, and excretory openings, as well as peculiar bristle-like **setae.** These latter will be discussed under locomotion.

The earthworm, like the frog, is bilaterally symmetrical. A median dorso-ventral line drawn through the worm divides it into two equal parts. This will be understood the better when it is remembered that all unpaired parts of the animal, such as mouth, anus, central blood vessel, etc., would be cut into two equal parts by a medial section, while all paired portions such as setae and reproductive openings would have one-half of such paired portion on each side of the animal.

The **dorsal excretory pores,** one to each somite posterior to the tenth, lie in the constrictions and are difficult to find, but on the ventral surface various openings can readily be seen. These are principally, two pairs of minute pores between the ninth and tenth and the tenth and eleventh somites coming from the **seminal receptacles.** The **male genital openings** are on the fifteenth and the pair of **female genital openings** on the fourteenth; the **excretory organs,** called **nephridia,** have two openings on each somite behind the first three or four and anterior to the last. Practically all of the ventral openings posterior to the male genital pore, with the exception of the anus, are too small to be seen with the unaided eye.

The animal moves along primarily by alternate rhythmic constrictions of the longitudinal and circular muscles of the body-wall which contract and elongate successive regions of the body. There are eight chitinous **setae** to each somite, easily felt if the animal be drawn between the fingers. An ordinary hand-lens will show them quite clearly. There is then a double way in which the worm moves, the muscular action furnishing the contraction and expansion and the setae furnishing cog-like projections by which the worm can make forward progress. This is well exemplified by the fact that if an earthworm be placed on a highly polished surface there is little if any progress made by it.

Muscles are attached to the inner parts of the setae, making it possible to shift their positions. The flattened tail of **Lumbricus terrestris,** serves as an anchor while the anterior portion of the animal's body lies on the surface of the earth.

INTERNAL STRUCTURE

Probably the earthworm illustrates a **coelom** (Fig. 162) as well as any form which could be given the student, for upon making either dorsal or ventral longitudinal incision the animal will give the appearance of a tube within a tube, the central one being the digestive tract held in its central position by little thin membranes or walls running from each outer constriction. These walls are called **septa** ( ) or **dissepiments** ( ). There are here, then, **many coelomic cavities** which can be clearly seen, it being remembered that a coelom is defined as the cavity lying **between the digestive tract and the outer body wall.**

There are muscles, nerves, glands, connective tissue, blood-vessels, epithelium, and endothelium, just as in the frog, though not developed as elaborately. There is also a delicate lifeless coat called the **cuticle.**

THE DIGESTIVE SYSTEM

The alimentary canal (Fig. 166) begins at the anterior end with a **mouth cavity** or **buccal pouch,** extending from the first to the third somite inclusively, the thick muscular **pharynx** ( ) lies in somites four and five; the **oesophagus,** a narrow straight tube, extends through the sixth to the fourteenth somite; a thick muscular-walled gizzard in somites seventeen and eighteen; and a thin-walled **intestine** from somite nineteen to the anal opening.

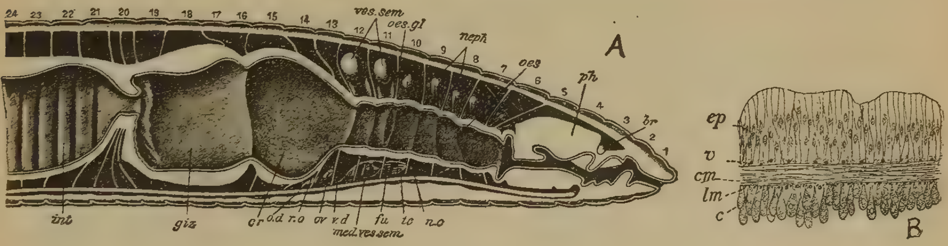


Fig. 166.

A, Longitudinal vertical section through the anterior portion of an earthworm. *br.*, brain; *cr.*, crop; *fu.*, seminal funnel; *giz.*, gizzard; *int.*, intestine; *n.c.*, nerve cord; *neph.*, nephridia; *oes.*, oesophagus; *oes. gl.*, oesophageal gland; *ph.*, pharynx. (From Parker and Haswell after Marshall and Hurst).
B, Section of the Alimentary Canal, *c*, chlorogogen cells; *cm*, circular muscles; *ep*, epithelium, lining the canal; *lm*, longitudinal muscles; *v*, blood vessels. (From Conn, modified from Sedgwick and Wilson).

The dorsal wall of the intestine is folded in, forming a longitudinal ridge, called the **typhlosole** ( ). This gives the intestine considerable expansion and affords additional surface for digestion.

The wall of the intestine, as in the frog, is composed of five layers. (Fig. 166, B):

(1) An inner lining of ciliated epithelium,
(2) A vascular layer containing many small blood vessels,
(3) A thin layer of circular muscle fibers,
(4) A layer consisting of a very few longitudinal muscle fibers,
(5) An outer thick coat of **chlorogogen** cells ( ) modified from the coelomic epithelium.

It is supposed that, because these chlorogogen cells lie in the typhlosole close to the dorsal blood vessel that they may aid in some digestive process. Then, because chlorogogen granules are present in the coelomic fluid of adult worms and make their way to the outer part of the body through the dorsal pores, it has likewise been suggested that they may have some excretory function.

Three pairs of **calciferous glands** ( ), one pair in each of the somites from ten to twelve are found at the sides of the oesophagus. The first pair are pouches pushed out from the alimentary canal which open directly into the oesophagus. The other two pairs are swellings of the oesophageal wall. They have a number of small cavities which open directly through the epithelium into the oesophagus in somite fifteen.

One writer thinks these glands manufacture carbonate of lime which is then secreted into the alimentary tract to neutralize the acid foods, while another suggests that the primary function of the glands is merely to excrete calcareous matter derived from leaves on which the animal feeds. This opinion he bases on the fact that such matter accumulates in leaf-tissue and remains in the leaf when it falls. The worms taking in large quantities of calcareous matter but having no shell or bone, there is no use for it, and so "some special excretory apparatus seems necessary." This latter opinion does not oppose the one given immediately preceding it. But the gizzard and intestinal content of worms is, as a rule, acid, so this would seem to oppose both of the above ideas. However, this acidification "may be the result of fermentations occurring in the later stages of digestion."

It will thus be seen, that many things must be considered before one can speak on subjects such as these with any degree of authority and positiveness.

As stated, the earthworm feeds on decaying leaves and animal matter. This food is sucked into the buccal cavity.

Here it receives a secretion from the pharyngeal glands, after which it passes through the oesophagus to the crop to be stored temporarily. Secretions from the calciferous glands in the oespohageal walls neutralize the acids. The gizzard is a grinding organ in which the food is broken up into minute fragments by being squeezed and rolled about. Then, too, solid particles, such as rough pebbles, which are frequently swallowed, may aid in the grinding process. The food then passes to the intestine, where most of the digestion and absorption takes place.

Digestion in the earthworm is very similar to that of higher animals. The digestive fluids act upon **proteins, carbohydrates,** and **fats**; in them are special compounds called **ferments** or **enzymes,** which break up complex molecules without themselves becoming changed chemically. The three most important enzymes are (1) **trypsin** ( ), which dissolves protein; (2) **diastase** ( ), which breaks up molecules of carbohydrates, and (3) **steapsin** ( ), which acts upon fats. These three enzymes are probably in the digestive fluids of the earthworm. The proteins are changed into peptones, the carbohydrates into a sugar compound, and the fats are divided into glycerin and fatty acids."

After this process has taken place the food is ready for absorption. This takes place through the wall of the intestine by **osmosis,** assisted by an **amoeboid activity** of some of the epithelial cells.

It will be remembered from our study of the frog that all parts of a living organism must be nourished. The food absorbed is now taken into the circulation and made an actual part of the blood. As there are no blood vessels in some parts of the earthworm, some of the absorbed food is also taken into the coelomic fluid so as to bathe the bloodless areas.

THE CIRCULATORY SYSTEM

The blood of the earthworm, unlike that of man, is actually red, while the corpuscles are colorless. In man the blood-liquid is colorless and the corpuscles floating about in the blood-plasma are red. This means that the pigment **haemoglobin** ( ) is **within the corpuscle in man** and the higher animals, while it is **in solution in earthworms.**

The following table mentions most of the important longitudinal blood-vessels (Fig. 167):

(1) The **dorsal** or **supra-intestinal,** running along the dorsal surface of the alimentary canal, from the posterior end of the body to the pharynx. It then divides into many small branches.

(2) The **ventral** or **sub-intestinal** trunk lying just beneath the alimentary canal. It also extends from the posterior end of the body to the pharynx where it divides into many small branches.

(3) The **sub-neural trunk,** as its name implies, passes along under the ventral nerve cord the entire length of the body.

(4) A pair of **lateral-neural trunks** (smaller than those above) lying, one on each side of the ventral nerve cord.

As in the frog and all other vertebrates, **paired** arteries, veins, and nerves, pass out of and into the spinal cord between the various vertebrae, so in each segment of the earthworm tiny branches of the dorsal and ventral trunks called **parietal** ( ) branches pass along the various septa dividing the somites, and connect with the body wall, where they split unto fine branching **capillaries** supplying and draining the dermal musculature and epithelium.

Capillaries from the dorsal branch also supply the digestive tract, while in the anterior region two lateral vessels supply the reproductive organs.

It will be remembered that in the study of the frog, the circulatory system began with a three-chambered heart. In the earthworm there is no separate and distinct organ such as the heart. In its place there

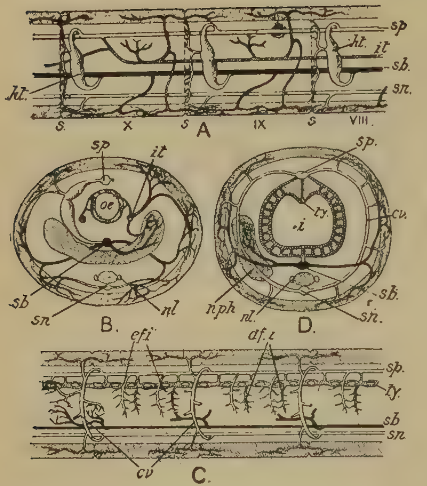


Fig. 167.

A series of diagrams to illustrate the arrangement of the blood-vessels and the course of the circulation in *Lumbricus herculeus*. *A*. Longitudinal view of the vessels in somites 8, 9 and 10. *B*. The blood-vessels as seen in transverse section in the same region. *C*. Longitudinal view of the vessels in the intestinal region. *D*. Transverse section through the intestinal region. *sp*, supra-intestinal; *sb*, sub-intestinal, and *sn*, sub-neural longitudinal trunks; *nl*, lateral neural vessels; *ht*, *ht*, contractile vessels or "hearts;" *it*, intestino-tegumentary vessels; *cv*, commissural vessels; *af.i*, afferent intestinal vessels; *ef.i*, efferent intestinal vessels; *ty*, typhlosolar vessel; *i*, intestine; *oe*, oesophagus; *s.s.* septa. (After Bourne from a drawing by Dr. W. B. Benham).

are **five pairs of enlarged vessels** called **aortic arches, aortic loops,** or **"hearts,"** running from dorsal trunk to ventral through the seventh, eighth, ninth, tenth and eleventh somites.

These "hearts," as well as the dorsal trunk, furnish the muscular contraction and elongation of circular and longitudinal muscles which force the blood through the vessels. Such rhythmic contraction and expansion in either blood vessels or intestines is known as **peristalsis** ( ).

In the frog there is a **systemic** and **pulmonary circulation.** The earthworm possessing no lungs can have no pulmonary circulation.

The blood of the earthworm is **continuous** in closed blood-vessels, so it is called a **closed systemic circulation.**

But just as there is the closed circulation consisting of heart, arteries, veins and capillaries in the frog, as well as a **lymphatic, open circulation,** by which the lymph passing out of the blood-vessels is able to bathe every part of the body, so we speak of a **coelomic circulation** in the earthworm, which is equivalent to the lymph-like substance outside of the blood-vessels, but within the coelomic cavity of the frog.

The blood is collected from the intestine by two pairs of vessels which enter a longitudinal **typhlosolar tube.** This tube is in turn connected with the dorsal trunk by three or four short tubes in each somite.

As there are no circular muscles in the walls of the ventral trunk this cannot contract, so the propelling of blood is caused by the dorsal trunk and "hearts" as already stated. This ability of the dorsal trunk and "hearts," together with the fact that there are valves in both of these vessels which permit blood to flow forward but not backward, determines the direction of flow. These valves are just behind the openings of the parietal vessels and in front of the openings of the hearts. There are other valves also, in some of the other vessels, but these just mentioned are most important to show how and why the blood flows as it does.

The blood must, therefore, flow forward toward the anterior end of the animal in the dorsal trunk. It is thus forced through the "hearts" and, as it reaches the ventral trunk, is sent both in an anterior and a posterior direction. From the ventral trunk the blood passes to the body wall and nephridia. The lateral neural trunks then receive the blood which has gone to the body-wall, while that having gone to the nephridia has been expelled. The blood in the sub-neural trunk flows posteriorly, then upward through the parietal vessels into the dorsal trunk. The anterior portion of the body receives its nourishment from both dorsal and ventral trunks.

The **Coelomic circulation** consists of the fluid in the coelomic cavities. These cavities are continuous throughout all the somites through dorsal apertures or slits occurring between the various septa and the digestive tract. The fluid itself is made up of colorless plasma with white blood cells or **leucocytes** ( ). This fluid is washed back and forth by the movements of the worm and thus bathes the **endothelial lining** of the coelom.

The amoeboid corpuscles in the coelomic fluid have a remarkable power of attacking bacteria and other microscopic organisms such as Gregarines and Infusorians or even small Nematode worms. If such parasites enter the coelom the amoeboid cells surround and destroy them. Their operations are, however, not confined to the inside of the earthworm. The slime of the body surface is in part composed of mucus secreted by the skin, and in part of coelomic fluid and its corpuscles which find exit through the dorsal pores. The corpuscles are thus able to attack and destroy bacteria before they effect an entry into the body. There is no doubt that a worm is constantly exposed to these minute organisms for the upper layers of the soil teem with them. The slime itself is a protection, for it both arrests the bacteria and holds them stranded in the trail which the worm leaves behind it in its progress. The application of a grain of some irritant, such as corrosive sublimate, enables one to see how a worm protects itself. As soon as the irritant touches the skin the segments in front and behind the seat of injury are forcibly constricted, while the affected segment itself swells up in consequence of the increased pressure brought to bear upon it from both sides. At the same time there is a conspicuous gush of coelomic fluid from the dorsal pores in that region and an abundant secretion of mucus from the skin itself. Thus the threatened region is, as it were, isolated by ligatures from the rest of the body and all the defensive resources at once brought to bear upon the enemy. The coelomic fluid is alkaline and contains crystals of calcium carbonate, and also contains micro-organisms which when isolated and reared in artificial cultures emit the characteristic smell of earthworms. It is, therefore, not improbable that this odor is due to the micro-organisms and not really a feature of the worm itself.

From what has been said above it will be seen that there is in reality **no true circulation** in the earthworm.

RESPIRATION

The earthworm needs oxygen just as do all animals; but, as it has no lungs it obtains its oxygen through its **moist outer membrane.** There are many capillaries lying immediately beneath the cuticle, thus presenting a great expanse of blood area which is somewhat similar to the many capillaries in the lungs of higher forms. The oxygen here combines with haemoglobin. The blood gets to these capillaries through the vessels supplying the body wall and is then returned to the dorsal trunk by way of the sub-neural trunk and the intestinal connectives.

As the nervous system must **co-ordinate** every movement of the body, it requires an excellent blood-supply, which is furnished the better in the earthworm by the sub-neural trunk lying very close to the ventral nerve cord. The nervous system is thus continually supplied with fresh nourishment.

THE EXCRETORY SYSTEM

Most of the excretory matter is carried outside the body by a number of **coiled tubes** called **nephridia,** a pair of which lies in each somite except the first three and the last. The dorsal pores also serve as excretory organs to a minor extent.

A clear understanding of the nephridia is important, because such an understanding will serve the student in good stead in his future studies of the excretory organs of vertebrates. This is the better understood when it is known that the excretory organs of all higher forms develop from embryological beginnings quite similar to those of the earthworm.

Each nephridium (Fig. 168) consists of:

(1) The funnel or **nephrostome** ( ),
(2) The **ciliated neck,**
(3) The **coiled narrow tube,**
(4) The **wide glandular tube,**
(5) The **ejaculatory duct** opening to the outside.

"The ciliated neck of the nephrostome passes through the anterior wall of the somite, close to the mid-ventral line. The nephrostome, therefore, lies in the somite anterior to the one containing its own nephridium, so that waste matters of any one somite are expelled to the outside by the nephridium of the next posterior somite. The nephrostomes, or mouths, of the nephridia are flattened fan-like structures, consisting of two flattened lamellae or plates with a narrow slit-like opening between them; the great cells lining the opening are covered with powerful cilia which maintain a constant current toward the tubular part of the nephridium. These tubes are developed in coils which lie in the posterior parts of the somites, three coils or turns in each, the third ending in an enlarged portion opening to the outside on the ventral wall of the somite. All of the turns are richly supplied with blood vessels.”

An excellent way to demonstrate the action of these nephridic organs is that of injecting carmine powder into the coelom. It will then be observed that this foreign substance is taken up by the chlorogogen cells, which then break down, freeing the carmine together with fragments of the chlorogogen cells, and all are caught up by the current made by the nephrostome, and carried through the nephridium to the outside. From this experiment the conclusion has been drawn that some, at least, of the waste matters of the tissues are brought to the chlorogogen cells by the circulation and are acted upon by the fluids of those cells. The products of this activity are liberated into the coelom by the fragmentation of the cells, and then excreted from the worm by the nephridia.

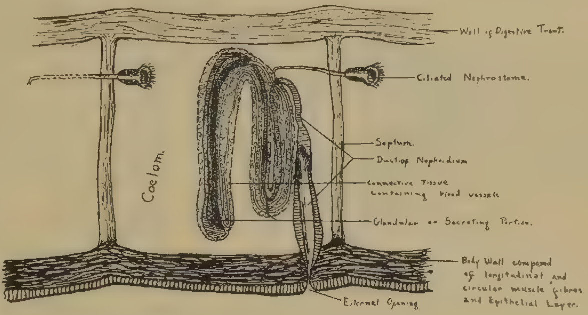

Wall of Digestive Tract.
Ciliated Nephrostome.
Coelom.
Septum.
Duct of Nephridium
Connective Tissue containing blood vessels
Glandular or Secreting Portion.
Body Wall composed of longitudinal and circular muscle fibres and Epithelial Layer.
External Opening

Fig. 168. *Nephridium.*

THE NERVOUS SYSTEM

Notwithstanding the nerve cells scattered about in the Hydra, it is in the Earthworm that we meet with our first **organized nervous system** (Fig. 169). That is, of course, excluding our study of the frog. And it will be remembered that the nerve cord was on the dorsal side of the frog. In the earthworm, and all animals lower than vertebrates, it lies on the ventral surface. This is quite important and will be of use in our later study of evolutionary theories.

Nerves are sensory, motor, or mixed as noted in the frog. Both sensory and motor nerves run to the muscles of the earthworm, causing reflex action. A reflex action means that an impulse sent toward the central nervous system through a sensory nerve, meets a motor nerve (the meeting place being called a **ganglion**), and the motor impulse is then returned to the place from whence the sensory impulse originated, permitting an organ to move. If such ganglion lies in the **lower** nerve centers, that is, if it lies **caudad to the brain**, so that an impulse from a sensory fiber need not first pass to the brain before meeting the motor fiber, it is called a reflex.

The ventral nerve cord is in reality a **series of ganglia,** one pair lying in each somite posterior to the fourth. Each pair is connected by a nerve cord to the one preceding and following it. In somite four this nerve cord divides into two parts, one passing on each side of the alimentary tract to again unite above the pharynx in the third somite. This **dorsal union** is the **brain,** while the two portions forming it are known as the **circum-pharyngeal connectives.** The segmental ganglia forming the nerve cord are called the **sub-pharyngeal ganglia.** The brain and ventral cord form the **central nervous system.** The nerves passing from the central nervous system to the various parts of the body constitute the **peripheral nervous system.**

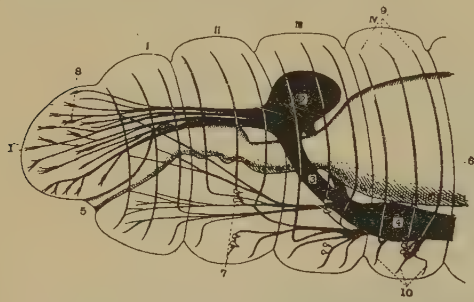


Fig. 169. Diagram of the Anterior End of *Lumbricus Herculeus* to show the Arrangement of the Nervous System.
I, II, III, IV. The first, second, third, and fourth segments.
1. The prostomium. 2. The cerebral ganglia. 3. The circumoral commissure. 4. The first ventral ganglion. 5. The mouth. 6. The pharynx. 7. The dorsal and ventral pair of chaetae. 8. The tactile nerves to the prostomium. 9. The anterior, middle and posterior dorsal nerves. 10. The anterior, middle and posterior ventral nerves. (After Hesse).

The supra-pharyngeal ganglia supply the prostomium with two large nerves which give off many branches; they also send nerves into somites two and three. One nerve extends out from each circum-pharyngeal connective. In each somite from four to the posterior end of the body, three pairs of nerves arise, two pairs from the ganglionic mass and one pair from the sides of the nerve cord just behind the septum which separates the somite from the one preceding.

Each enlargement of the ventral nerve cord really consists of two ganglia, which are closely fused together. In transverse section these fused ganglia are seen to be surrounded by an outer thin layer of epithelium, the peritoneum, and an inner muscular sheath containing blood vessels and connective tissue as well as muscle fibers. Near the dorsal surface are three large areas, each surrounded by a thick double sheath and containing a bundle of nerve fibers. These are called neurochords or "giant fibers." Large pear-shaped nerve cells are visible near the periphery in the lateral and ventral parts of the ganglion.

The nerves of the peripheral nervous system are **either efferent or afferent.** Efferent nerve fibers are extensions from cells in the ganglia of the central nervous system. They pass out to the muscles or other organs, and, since impulses sent along them give rise to movements, the cells of which they are a part, are said to be motor nerve cells. The afferent fibers originate from nerve cells in the epidermis which are sensory in function, and extend into the ventral nerve cord.

SENSE ORGANS

The sensitiveness of Lumbricus to light and other stimuli is due to the presence of a great number of epidermal sense organs. These are groups of sense cells connected with the central nervous system by means of nerve fibers, and communicating with the outside world through sense hairs which penetrate the cuticle. More of these sense organs occur at the anterior and posterior ends than in any other region of the body. The epidermis of the earthworm is also supplied with efferent nerve fibers which penetrate between the epidermal cells forming a sub-epidermal network.

THE REPRODUCTIVE SYSTEM

The earthworm, like Hydra, is **hermaphroditic** (Fig. 170) ( ), that is, has both sexes in each animal.

The female reproductive organs, the **ovaries**, lie in somite thirteen, the oviducts in somites thirteen and fourteen, while two pairs of **seminal receptacles** or **spermathecae** lie in somites nine and ten.

The ovaries are small pear-shaped bodies lying on either side of the mid-ventral line, being attached by their larger ends to the ventral part of the anterior septum.

The oviducts are made up of various parts: the ciliated funnel just posterior to each ovary which passes through the septum, dividing somites thirteen and fourteen, where it has an enlargement known as the egg sac. It then narrows into a thin duct which opens to the external part of the body on the ventral surface near the center of somite fourteen.

The **spermathecae** or **seminal receptacles** are white spherical sacs near the ventral body-wall, one pair each in somites nine and ten. These open to the outside through the spermathecal pores lying between somites nine and ten, and ten and eleven.

The male reproductive organs consist of two pairs of glove-shaped **testes**, one pair each in somites ten and eleven. Their positions in the somites are similar to the ovaries. The **vas deferens** ( ), the male organ **homologous** to the female oviduct, is likewise a ciliated funnel serving as the mouth of the duct through which the sperm pass. This lies immediately behind each testis. The duct itself passes through the septum just back of the funnel, where it forms several convolutions, then extending backward near the ventral surface. The two sperm ducts which arise on either side of the midventral line, unite in somite twelve and then run back as a single tube, opening to the outside through the **spermiducal** pore on somite fifteen. In a sexually mature earthworm, the testes and funnel-shaped inner openings of the sperm ducts are in-closed by large white sacs, the **seminal vesicles** lying in somites nine to twelve. There are three pairs of these sperm sacs, one in somite nine, one in somite eleven, and the third in somite twelve. In somites ten and eleven there are central reservoirs.

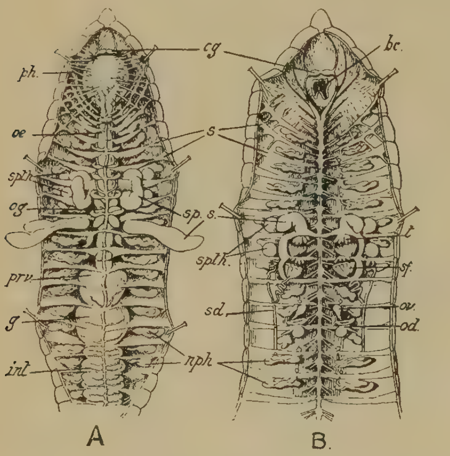


Fig. 170. *Lumbricus Herculeus.*

A. A view of the organs contained in the first twenty-two somites, as seen when the animal is opened by a longitudinal dorsal incision, and the body walls are pinned out without cutting the septa. The pins are placed in the 3rd, 9th, and 18th somites. *B.* View of the first sixteen somites of the same worm after removal of the alimentary tract, to show the nervous system and reproductive organs. *bc*, buccal cavity, cut across; *cg*, cerebral ganglia; *g*, gizzard; *int*, intestine; *nph*, nephridia; *od*, oviduct; *oe*, oesophagus; *ov*, ovary in somite 13; *ph*, pharynx with radiating muscular strands; *prv*, proventriculus; *s*, septa; *sd*, sperm duct; *sf*, seminal funnels; *spth*, spermathecae in somites 9 and 10; *sp.s*, sperm sacs; *t*, testis. (After Bourne).

The testes are rather difficult to find in a mature worm because they are quite small and the dorsal wall of the vesicle must first be removed.

The sperm are developed in the testes and stored in the seminal vesicles from which they are, during the period of copulation, injected into the seminal receptacles of another worm. Fertilization actually taking place **outside the body,** however.

When the earthworm is sexually mature there is a **clitellum** or **cingulum** formed, covering some six or seven segments. This is a thickened portion often supposed to be a scar formed by the worm after having been injured or cut in two. Mating may take place at any season of the year, but occurs more frequently in warm damp weather.

Again quoting Latter: Two worms from adjacent burrows, "each retaining a firm hold in its own burrow by means of the flattened tail, apply their ventral surfaces to one another so as to overlap for about a third of the length of the body. The head of each worm points toward the tail of the other. The clitellum of each secretes a band of mucus which binds the two worms firmly together, so firmly, indeed, as to cause two well-marked constrictions, while a slimy covering, the slime tube, surrounds the two worms from the 8th to the 33rd segments. The seminal fluid, containing **spermatozoa** (   ) and **spermatophores** (   ), flows within the slime-tube, and during sexual union, in the early stages of the formation of the cocoons spermatophores cover the dorsal and lateral surfaces of segments 9, 10, and 11 of each worm and are packed between the two worms. The spermatozoa flow backwards from the male aperture in a longitudinal groove on each side to the receptacula (spermathecae) of the other worm, the grooves of the two animals together forming a temporary tube. Hence only one worm can emit spermatozoa at any given time, otherwise there would be opposing currents. The worms are so placed that the 9th segment of each is opposite the 32nd (1st clitellar) of its mate, then the thickened clitellum forms a barrier past which no flow of seminal fluid can take place."

'The long genital setae in the 'tubercula pubertatis' ( ) of the clitellum, and of segments 10 to 15, are probably used, the former to liberate the cocoon from its seat of origin, and the latter series to hold the cocoon off the ventral surface in the region of the oviducal openings and those of the spermathecae, and thus allow ova and spermatophores to pass into the cocoon as it passes forwards. These specialized setae replace those of ordinary form as the worm reaches maturity. The eggs do not pass out of the oviduct till near the end of the act of mating. Each of the two worms forms a cocoon, and slips out of it backwards, passing it forward over its head. The cocoon being elastic closes its two open ends as soon as the body of the worm is withdrawn, and becomes more or less lemon-shaped, its bulging center being occupied by about four eggs, spermatozoa and albuminous material produced by the so-called capsulogenous glands, which may be seen on the ventral side of some of the segments in front of the clitellum. The cocoons, at first white but soon becoming yellow, are left in the earth, and as a rule only one of the contained eggs produces a young worm. The size of the cocoons differs in the various species, those of L. terrestris are from 6 to 8 mm. long by 4 to 6 mm. broad, of Eisenia foetida from 4 to 6 mm. long by 2 to 3 mm. broad. There is some doubt as to the precise function of the spermathecae. It seems certain that the spermatozoa contained in them are derived from some other worm. It is also the case that these organs are full of spermatozoa prior to sexual union, and are empty subsequent to that act, at any rate when cocoons are formed and eggs deposited. Worms have been observed to separate without producing cocoons, and though perhaps in some instances the separation may have been due to disturbance caused by observation, yet there is reason to think that two unions are necessary, one to fill the spermathecae, and a second to form cocoons. In such a case it is probable that each worm acts as a carrier of spermatozoa from its first to its second mate, i. e., worm A gets its spermathecae filled by the spermatozoa of B in the first union, and passes these spermatozoa to C in the second. The actions are probably often reciprocal. According to Goehlich, while spermatozoa are flowing from one worm to the spermathecae of the other, there is given out from the spermathecae of the former a small quantity of mucus which hardens when it reaches the air: a second portion of mucus containing a group of spermatozoa is then emitted, this becomes attached to the first mass, and with it forms a spermatophore. The whole spermatophore is attached to the body of the other worm close to the clitellum. When the cocoon is made the spermatophores are rubbed off into it as the animal withdraws itself.

"Light could probably be thrown on this matter by some such experiments as follow: keep a number of worms, each in a separate flower-pot, from infancy to maturity; kill a few and examine the contents of their spermathecae (it is conceivable that a worm may be able to pass spermatozoa into its own spermathecae); allow remainder to mate once, note if cocoons are deposited; kill some and examine contents of spermathecae; allow rest to mate a second time, pairing some with their former mates and others with different mates: kill all and examine spermathecae."

In plants and animals where both sperm and eggs are found in the same individual there is usually a different period for the maturing of each or some apparatus like this of the earthworm is brought into play so that it is very seldom that the same organism can fertilize itself.

The **sperm-mother cells** are derived from the testes and deposited in the seminal vesicles. They are not fully developed, or as we say, "mature," however, when they leave the testes, and so must continue their development in the seminal vesicles.

The sperm-mother cells or **primordial germ-cells** from which the sperm are developed in the testes, have their nuclei divide into 2, 4, 8, or 16 daughter nuclei which become arranged in a single layer near the periphery of the protoplasm which has not divided. Cell walls then appear extending inward into the undivided protoplasmic mass. These newly-formed cells now divide again, forming as high as from 32 to 128 cells when the whole mass breaks up into smaller colonies. These nucleated cells which are to become sperm are called **spermatogonia.** These spermatogonial colonies become spherical, each containing 32 primary **spermatocytes,** all of which are still fastened by **cytoplasmic threads** to the central protoplasm. This whole 32 celled colony is now called a **blastophore.**

Each colony of primary spermatocytes "gives rise to 64 **secondary spermatocytes,** and these divide into 128 **spermatids.** The latter then **metamorphose** ( ) into **spermatozoa.** The number of chromosomes in the spermatozoa is sixteen; this is one-half the number contained in the **somatic cells,** the reduction having taken place during **maturation** by the union of the chromosomes two by two in the secondary spermatocytes, and a subsequent separation when the spermatids were formed."

The head of the spermatozoon is practically all nuclear material, the mid-piece is what was formerly the centrosome, while the cytoplasm formed the tail. But as it is only the head which actually enters and fertilizes the egg, the tail being used only for locomotive purposes, it will be seen why nuclear material is considered so very important.

OOGENESIS

The egg-mother cells are found in the ovary in various stages of growth, beginning at the basal end of each ovary with the most primitive germ-cells, the ova increasing in size toward the extreme end, where the germ-cells are distinctly recognizable as eggs. Each egg is surrounded by a follicle (   ) of nutritive cells. The eggs separate from the end of the ovary dropping into the body-cavity, then passing into the ciliated end of the oviduct which goes to the egg-sac where part of the maturation takes place. From here they either pass out into the cavity of the slime-tube and are conveyed from the external openings of the oviduct in somite 14 to the cocoon, or they enter the cocoon itself when it passes over this somite during deposition, the eggs actually being fertilized by the spermatozoa after the cocoon is shed, and before the egg has completed its maturation process.

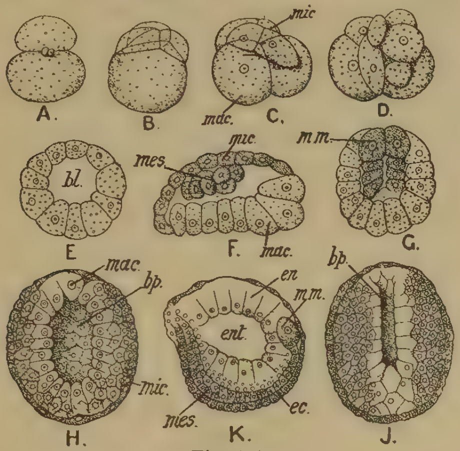


Fig. 171.

Segmentation and early stages of development of *Lumbricus*. *A, B, C, D,* successive stages of segmentation. *E.* Blastula stage. *F.* Commencement of invagination; the macromeres form a flat plate on the ventral side. *G.* An embryo somewhat younger than *F* viewed from above, showing the mesomeres and mesoblast rows derived from them. *H.* Gastrula stage viewed from below, showing the wide oval blastopore bounded by macromeres; at the sides the micromeres are growing over the macromeres. *J.* Later stage, showing the elongated blastopore and the further overgrowth of the macromeres by the micromeres. *K.* Optical longitudinal section through a later stage after the closure of the blastopore. *bp*, blastopore; *ec*, ectoderm; *en*, endoderm; *ent*, enteron; *mac*, macromeres; *mes*, mesoblast; *mic*, micromeres; *mm*, mesomeres. (From Bourne after Wilson.)

EMBRYOLOGY

The egg of the earthworm is **holoblastic** (Fig. 171) although **cleavage is unequal,** the first division resulting in one large and one small cell. The second cleavage divides the small cell into two equal parts but cuts off only a small portion from the larger one. The small cells are called **micromeres** and the large ones **macromeres.** Cleavage is very irregular after this second division. The micromeres are the **animal cells** and the macromeres the **vegetative cells.**

A cavity, the **blastocoele,** soon forms between micromeres and macromeres resulting in a **blastula.**

Two of the larger cells of the blastula project down into the blastocoele. These continue dividing and form two rows of small cells from which the mesoderm is to form. They are therefore called **mesomeres,** while the two rows formed from them are known as **mesoblastic bands.** During the time these bands are forming the blastula becomes flattened, the larger cells forming a plate "of **clear columnar cells**, and the small cells spread out into a thin dome-shaped **epithelium.**"

The mesomeres lie toward the posterior end of the blastula and the mesoblastic bands lie along the **longitudinal axis** of the worm, showing the beginnings of **bilateral symmetry.**

A gastrula is now formed by the **invagination** of the plate of large cells, this invagination continuing until only a slit remains. This tiny opening or slit is called the **blastopore,** while the cavity is the **enteron.**

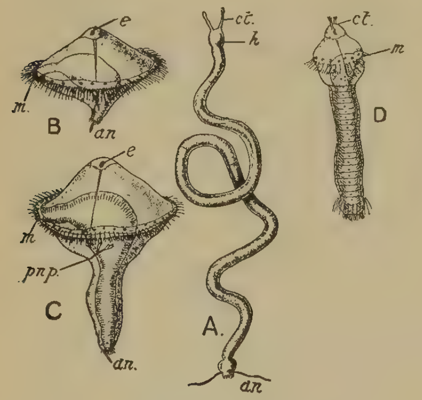


Fig. 172. *Polygordius Appendiculatus.* A, dorsal view. *an,* anus; *ct.,* cephalic tentacles; *h,* head. B, trochosphere larva. *an,* anus; *e,* eye-spot; *m.,* mouth. C and D, stages in development of trochosphere into the worm. *pnp,* pronephridium. (From Bourne, after Fraipont).

Fig. 173. *Nereis Pelagica,* L. (After Oersted).

There are now **three germ-layers.** The mid-layer or **mesoderm** already began forming **before gastrulation.**

The large clear cells which invaginated have become the inner lining of the enteron and form the **entoderm**; the outer portion is **ectoderm,** while the **mesoderm** is made up of the two mesoblastic bands which lie between ectoderm and entoderm.

As the earthworm is to be our example of the **coelomates** it is of value here to observe how the coelom is formed.

The mesoderm separates into the two layers on each side of the body. A cavity forms between these layers. **This cavity is the coelom.** The outer portion of the divided mesoderm is called the **somatopleure** (   ), the inner layer the **splanchnopleure** (   ).

The **muscles of the body-wall** are formed **from the somatopleure,** while **the splanchnopleure forms the muscles of the alimentary canal.** After the germ-layers are formed, the embryo elongates, the anterior-posterior axis passing through the blastopore. There are various **in-pushings from the ectoderm** which become the **elements of the nervous system.** Such beginning cells are called **neuroblasts** if they form **nerves.**

There are also **separations from the mesoderm** forming **nephroblasts** if they form nephridia, **somatoblasts** which form muscles, etc.

The ectoderm turns in at both anterior and posterior ends, the former forming the mouth or **stomodeum** ( ), the latter the anal opening or **proctodeum** ( ).

The **chlorogogen cells** are formed **from mesoderm,** as are also the **blood-vessels, muscles, reproductive organs** and **seta sacs.** The young worm is now ready for an independent life, and it leaves the cocoon after from two to three weeks.

The following table will give a summary of the important tissues derived from the various germ-layers:

ENTODERM	ECTODERM	MESODERM
Oesophagus,	Outer Epithelium,	Muscles,
Crop,	Nervous System,	Coelomic Endothelium,
Gizzard.	Stomodeum,	Chlorogogen Cells,
	Proctodeum,	Calciferous Glands,
	Ends of Nephridia.	Blood vessels,
		Septa,
		Nephridia, functional parts,
		Seta Sacs,
		Reproductive Organs.

BEHAVIOR

As already seen, worms are apparently fond of having their bodies in contact with solid objects as shown by their home-life. Moisture causes a positive reaction if such moisture comes in direct contact with the worm's body. This is well illustrated by placing the earthworm, **Allobophora foetida** (the small manure worm), on a piece of dry filter paper when it will not react, but as soon as moisture is applied it begins to burrow, provided this moisture or liquid is taken from manure.

Darwin supposed that the earthworm's ability to distinguish edible from inedible food lay in the sense of contact. This would make **contact** in the earthworm act as a sort of **taste organ.** Various chemicals which cause a reaction may be due to this sort of secondary taste-ability.

While there are no eyes, light causes the animal to react as shown by its moving away from lighted areas though the manure worm will respond **positively** to a very **faint light.** The preferable colors, when very faint, are red, green and blue in the order given, though it does not follow from this that the earthworm can distinguish colors; its ability consisting, in all probability, of "feeling" different rays of light as well as different intensities.

It has also been noted that if a previous stimulus is much stronger than a succeeding one, the first will naturally continue to react and cause either no reaction to a second or at least lessen such reaction. An example of this is found when the animal is feeding or mating. Light which under normal conditions causes a negative reaction, may have no effect whatever under such circumstances, the **instinctive reaction of the primary instinct** being stronger than the artificial secondary stimulus.

REGENERATION

Any part of an earthworm may be cut off at any point between the end of the prostomium and the fifteenth to the eighteenth segment and a new anterior end will grow out from the cut end of the body consisting of a single segment if only one segment was removed; two segments, if two segments were removed; and of three, four, or five segments, if three, four, or five segments were removed. But never more than segments one to five are regenerated, regardless of the number removed, and no new reproductive organs appear if the original ones were contained in the severed piece. If the cut is made behind segment eighteen, a tail will grow out from the cut surface of the posterior piece, thus producing a worm consisting of two tails joined at the center. Such a creature cannot take in food, and must slowly starve to death. When the regenerated part is different from the part removed, as in the case just cited, the term **heteromorphosis** is given to the phenomenon.

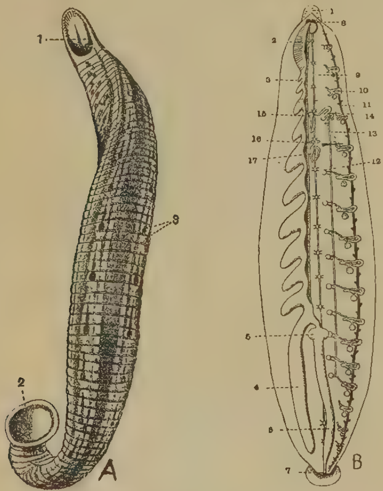


Fig. 174.

A. Hirudo medicinalis, about life size.
1. Mouth. 2. Posterior sucker. 3. Sensory papillae on the anterior annulus of each segment. The remaining four annuli which make up each true segment are indicated by the markings on the dorsal surface.

B. View of the internal organs of *Hirudo medicinalis.* On the left side the alimentary canal is shown, but the right half of this organ has been removed to show the excretory and reproductive organs.
1. Head with eye spots. 2. Muscular pharynx. 3. 1st diverticulum of the crop. 4. 11th diverticulum of the crop. 5. Stomach. 6. Rectum. 7. Anus. 8. Cerebral ganglia. 9. Ventral nerve cord. 10. Nephridium. 11. Lateral blood-vessel. 12. Testis. 13. Vas deferens. 14. Prostate gland. 15. Penis. 16. Ovary. 17. Uterus—a dilatation formed by the conjoined oviducts. (After Shipley and MacBride).

Regeneration of a tail differs from that of a head, since more than five segments can be replaced. The anal segment develops first, and then a number of new segments are introduced between it and the old tissue.

The rate of regenerative growth depends upon the amount of old tissue removed. If only a few segments of the posterior end are cut off, a new tail regenerates very slowly; if more are removed, the new tissue is added more rapidly. In fact, the rate of growth increases up to a certain point as the amount removed increases. The factors regulating the rate of regeneration have not yet been fully determined, although several possible explanations have been suggested.

GRAFTING

Pieces of earthworms may be grafted upon other worms without much difficulty. Three pieces may be so united as to produce a very long worm; the tail of one animal may be grafted upon the side of another, producing a double-tailed worm; or the anterior end of one individual may be united with that of another. In all such experiments the parts must be held together by threads until they become united.

The Annelida are divided into three classes, as follows:

(1) **Class Archiannelida** (Gr. **arche,** beginning—Lat. **annellus,** ring). The **Polygordius** (Fig. 172) is the typical example. This class is without **setae** or **parapodia.**

(2) **Class Chaetopoda** (Gr. **chaite,** bristle—**pous,** foot). **Nereis,** the common sand-worm, and the earthworm are classic examples. **Nereis** differs from the earthworm in having a pair of **chitinous jaws,** a **pair of tentacles,** and **two pairs of eyes** on the prostomium, as well as in having a pair of **palpi,** and four pairs of **tentacles** on the peristome. The **parapodia** are used for locomotion, while the **lobes of the parapodia** are well supplied with blood-vessels and serve as **gills.** Then, too, there are **jointed locomotor-setae** on each parapodium, while the muscles which move the parapodium are attached to two buried bristles, called **aciculae,** which serve as a sort of internal skeleton. The sense organs of **Nereis** are also developed more highly than those of **Lumbricus,** the tentacles serving as organs of touch, while the palpi are thought to act as organs of taste, and the eyes, of sight.

Nereis (Fig. 173) is the example of the **Sub-class** known as **Polychaeta** (on account of its many foot-like structures), while such worm-like water-animals as **Tubifex, Dero,** and **Nais,** usually serve as the example of the sub-class, **Oligochaeta** (having few setae).

(3) **Class Hirudinea.** (Lat. **hirudo,** leech.) These are worm-like animals living in fresh water and on land. They are commonly called **leeches.** They are flattened **dorso-ventrally.** The external segmentation does not correspond to the internal segmentation. The leeches are distinguished from the earth-worm by having definitely **thirty-three segments, two suckers** (one at each end), and **no setae** (except in one genus). They are hermaphrodites.

The most important example is the medicinal leech known as **Hirudo medicinalis** (Fig. 174), normally about four inches long, though capable of much contraction and expansion. Not only are these animals used to draw blood from patients, but Lambart advises against drinking water which is not filtered, especially in the tropics, as the small leeches may be swallowed. They then attach themselves below the larynx and instead of releasing themselves when filled with blood as they do on an external surface, they seem to draw a small amount of blood and then migrate to another spot close by and begin the same process, thus causing considerable **anaemia** (loss of blood).

This is readily understandable when it is realized that the leech has three chitinous jaws to form the mouth (which lies within the anterior sucker). These jaws bite into a region, and a secretion from the mouth-glands is poured out which prevents the host's blood from coagulating. It is thus difficult to stop the bleeding after the animal has moved to a new location.

The digestive tract of the leech is especially adapted to the digestion of blood of vertebrates, upon which the leech feeds. There is a **muscular pharynx** and a **short oesophagus** leading to the **crop.** This crop has **eleven branches** or diverticulae. Then there is a **stomach,** an **intestine** and an **anus.** The leech can ingest about three times its own weight of blood.

There is a peculiar kind of connective tissue known as **botryoidal** ( ) **tissue** which develops in what should be the coelom. This body-cavity is therefore very small, although there are spaces in the coelom which are not filled with this tissue, these spaces being called **sinuses.**

There are **seventeen pairs of nephridia,** quite like those of the earthworm (except that they sometimes do not have an internal opening) which carry waste products from the coelomic fluid and from the blood. Respiration takes place at the surface of the body through the many blood-capillaries found in the skin.

There are **nine pairs of segmentally arranged testes** which empty their sperm into the **vas deferens,** then into a much-folded tubule called the **epididymis.** Here they are fastened into bundles known as **spermatophores.** They are then ready to fertilize the eggs of another leech, after passing out of the copulatory organ.

The eggs develop in a single pair of ovaries, from which they pass through the **oviducts** into the **uterus,** and finally out through the **genital pore** situated on the ventral side of the ninth segment. A cocoon is formed after copulation quite like that in earthworms.

CHAPTER XX.

FLATWORMS (PLATYHELMINTHES) AND THREADWORMS (NEMATHELMINTHES)

Systematically the flat worms and round worms should be placed before the earthworm as **they are not coelomates,** but, as the average man always thinks of a sort of segmented animal similar to an earthworm when worms are mentioned, and medical men likewise are not very accurate when they discuss these animals, the student is more likely to remember the three types of worms if he thinks of them all at once and notes their similarities and differences.

The Annelids are of little importance from a medical standpoint with the exception of the leech **(Hirudo Medicinalis)** commonly used to draw blood, but the flat worms and round unsegmented worms have come to have a very considerable bearing on the human being from a pathological standpoint.

THE FLATWORMS

The **flatworms** (which constitute the phylum **Platyhelminthes)** are subdivided into the following three classes:

Class I. **Turbellaria** (Lat. turbo, I disturb), with ciliated ectoderm; free-living habit, example: **Planaria.**

Class II. **Trematoda** (Gr. trema, a pore; eidos, resemblance), with non-ciliated ectoderm; suckers; parasitic habit, example: **Fasciola hepatica** (liver fluke), and

Class III. **Cestoda** (Gr. kestos, a girdle; eidos, resemblance), with body of segments; without mouth or alimentary canal; parasitic, example **Taenia** (tapeworm).

TURBELLARIA

Turbellaria are the only flatworms which are not parasitic. They live on the lower surface of submerged stones and debris close to the margin of ponds, springs and lakes. Most of these are **Planaria** (Fig. 175), but often a longer worm is found (from ten to fifteen millimeters) which is called **Dendrocoelum lacteum.**

Planaria crawls about among aquatic plants to seek its food. The cilia covering the ectoderm assist in this movement, though the animal also contracts and expands its body. As soon as a planarian finds a small animal suitable for its food, the **proboscis,** lying near the center of the body, is practically turned inside out through the mouth. This proboscis grasps the food and draws it into the body. As the mouth is near the center of the ventral surface, the proboscis can be extended in any direction.

The digestive system consists of the **mouth, proboscis or pharynx** (which lies in a muscular sheath), and three chief interior intestinal branches, one running forward to the head end of the body and two leading tailward. Many small side pouches or diverticula protrude. In fact, every part of the body has such a pouch. This means that all parts of the body can take nourishment immediately from the digestive tract so that planaria needs no circulatory system. All non-digested food must be egested through the mouth, as there is no anal opening.

In some forms a definite green substance appears which is due to **the zoochlorellae** or **symbiotic one-celled plants** which live in the middle germ-layer.

Food is digested both **intercellularly** and **intracellularly,** which means that a part of the food is digested **in the intestine proper** by secretions which are poured out from cells in the intestinal walls; and, that food may also be digested by pseudopodia extending from cells in the intestinal walls, which pseudopodia take in the undigested food to the cell which then digests it.

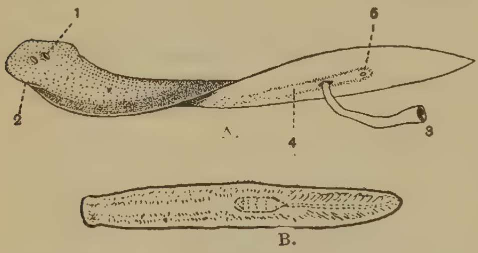


Fig. 175. *A. Planaria polychroa* × about 4.

1. Eye. 2. Ciliated slit at side of head. 3. Mouth of proboscis. 4. Outline of the pharynx sheath into which the pharynx can be withdrawn. 5. Reproductive pore.

B. Dendrocoelum graffi. (Woodworth).

External Appearance.

Planaria is bilaterally symmetrical and dorso-ventrally flattened. The head-end is blunt and the tail-end tapers. It is usually less than half an inch in length. The common American species is known as **Planaria maculata.** It has a definite pair of **eye-spots.**

Turbellaria are metazoans and triploblastic. The mesoderm consists mostly of muscles and loose parenchyma cells. The coelom is represented by the genital sacs.

Turbellaria are classified according to the type and number of branches found in the digestive tract.

In some of the turbellaria, though not in Planaria, there are special ectodermal cells which secrete mucus, or produce rod-like bodies called **rhabdites.**

The Excretory System.

The excretory system (Fig. 176) consists of two irregular longitudinal much-coiled tubes, one on each side of the body. Near the anterior end these two tubes are connected by a transverse vessel. The longitudinal vessels open to the exterior by two small pores on the dorsal surface of the animal.

Many fine tubules branch off from these main tubes and ramify through all parts of the body, terminating in large **flame-cells** (Fig. 177).

Each of these flame-cells (which are characteristic of the flatworms) consists of a central cavity into which a bundle of cilia project. The flickering of the cilia look something like a candle-flame, and it is from this fact they are named. It is the flame-cell which is considered the real excretory organ of the animal, though some writers think it may also have some respiratory functions.

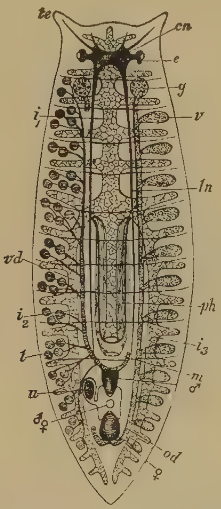


Fig. 176. Anatomy of a Flatworm.

cn, brain; *e*, eye; *g*, ovary; i_1, i_2, i_3, branches of intestine; *ln*, lateral nerve; *m*, mouth; *od*, oviduct; *ph*, pharynx; *t*, testis; *u*, uterus; *v*, yolk glands; *vd*, vas deferens; ♂, penis; ♀, vagina; ♂, ♀, common genital pore. (From Lankester's Treatise, after v. Graff).

The Nervous System.

There are two lobes (Fig. 176) of nervous tissue beneath the eye-spots. These are usually called the brain. There are also two longitudinal **nerve-cords,** one on each side of the body, connected by transverse nerves. Nerve branches pass into the head proper from the brain region, so that the anterior end becomes the more sensitive.

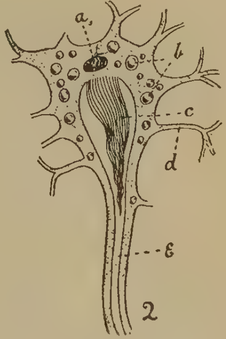


Fig. 177. Flame-cell of *Planaria.*

c, cilia; *e*, opening into the excretory tubule. (From Lankester's Treatise).

The Muscular System.

Immediately beneath the ectoderm, a group of muscles form a **dermo-muscular sac** around the internal organs. There are two layers, an inner longitudinal and an outer circular.

The Reproductive System.

Planaria are **hermaphroditic,** having both male and female reproductive organs (Fig. 176). These animals nevertheless often reproduce by **fission.** Each animal has numerous spherical testes which are connected by small tubules called **vasa deferentia.** The single vas deferens from each side of the body empties into, or through, the **cirrus** into the **genital cloaca.**

At the base of the cirrus there is a **seminal vesicle** and several unicellular **prostate glands.**

After the sperm are formed in the testes, they pass to the seminal vesicle through the vasa deferentia, and remain there until needed for fertilization.

The ovaries are two in number. From these the two long oviducts (which possess many yolk-glands) connect with the vagina The vagina opens into the genital cloaca. The uterus also connects with the cloaca.

After the eggs ripen, they pass from the ovary through the oviducts (where they collect yolk from the yolk-glands) and finally reach the uterus. Fertilization occurs in the uterus. Cocoons are formed, each containing from four to twenty eggs and several hundred yolk-cells.

As already stated, planaria may also reproduce by fission. This means in this instance that when the hindermost portion of the animal is grown, it breaks off from the fore part to produce a new animal.

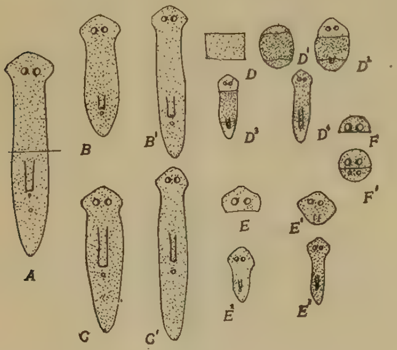


Fig. 178. Regeneration of *Planaria maculata*. *A*, normal worm. *B*, *B*¹, regeneration of anterior half. *C*, *C*¹, regeneration of posterior half. *D*, cross-piece of worm. *D*¹, *D*², *D*³, *D*⁴, regeneration of same. *E*, old head. *E*¹, *E*², *E*³, regeneration of same. *F*, *F*¹, regeneration of new head on posterior end of old head. (From Hegner after Morgan).

Regeneration.

From the laboratory point of view, Planaria is probably the most available animal one can find to show regeneration experiments. This is especially true because the parts to be regenerated grow very rapidly, each day marking a definite growth region.

Almost any part of the animal will re-grow, but there are portions quite specialized in **what** is re-grown. If, for example, the head is cut off directly behind the eyes, the more anterior part will regenerate a new head but no body, thus making a two-headed animal. Such specialization is called **polarity**. (Fig. 178.)

There are two types of eggs laid. In the summer the eggs are thin-shelled and develop quickly, while in the autumn the "winter eggs" are laid. These are thick-shelled and lie dormant until spring before hatching.

TREMATODA

All the trematodes are parasitic. Some are **monogenetic**; that is, the adults lay eggs which hatch into forms like their parents, all living on the outside of their host. These are said to have a **simple life-history**. This type of animal is usually found on cold-blooded vertebrates, such as frogs, fishes, etc.

The **endoparasitic** trematodes (those which live in the internal organs of a host, whether that be in the liver, lungs, intestines, bladder or other similar internal structure), are mostly **digenetic**. This means that the parasite must pass through more hosts than one to complete its life cycle.

The liver fluke, **Fasciola hepatica** (Fig. 179) is the form usually studied in the laboratory.

The adult liver fluke lives in the bile-ducts of the sheep's liver and is continually laying eggs which are carried through the intestine of the host to the outside in the faeces. If these eggs become moist they hatch into tiny **ciliated larvae** called **miracidia**. These larvae swim about until they find a **pond snail**. This being found, the larvae bore their way

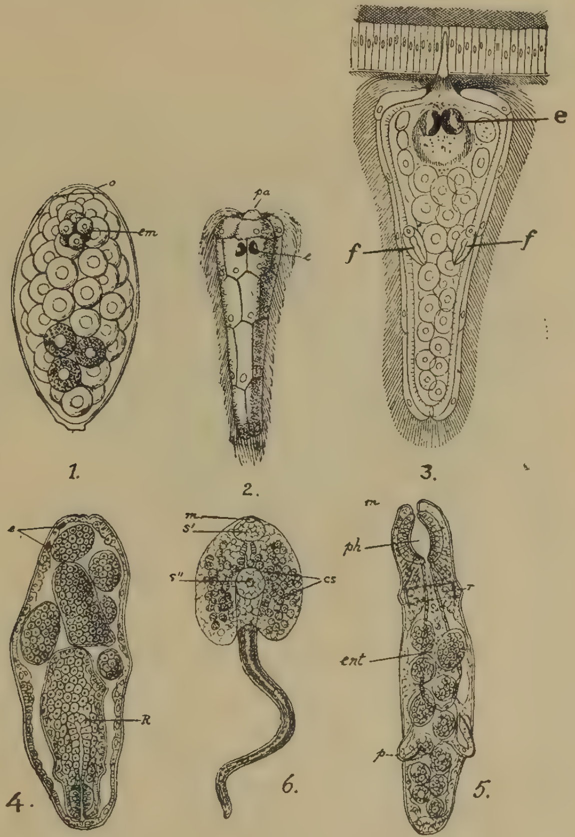


Fig. 179. Stages in the Life-History of the Liver Fluke, *Distomum Hepaticum.*

1, Egg filled with large vitelline cells in which the segmenting ovum, *em.*, is embedded; *o.*, operculum; 2, Miracidium larva with large ciliated cells, the eyespot *e.*, and the interior papilla, *pa.* 3, Miracidium boring its way into the tissues of *Limnaea; f-f.*, flame cells. 4, a sporocyst containing one fully developed and several developing rediae (*R.*); *e.*, the degenerate eyes. 5, a redia containing several daughter rediae in various stages of development; *m.*, mouth; *ph.*, pharynx; *ent.*, enteron; *r.*, muscle collar; *p.*, posterior processes. 6, a cercaria; *m.*, mouth; *s'.*, anterior, and *s''.*, posterior suckers; *cs.*, cystogenous cells. (After Thomas.)

into the snail where a complete change in the parasite takes place. It takes about two weeks for the fluke larvae to form a sac-like **sporocyst.** Each germ-cell in this sporocyst passes through a blastula and gastrula stage and then becomes a second kind of larva which is now called a **redia.** These **rediae** then break through the sporocyst and enter the host's liver. The rediae have germ-cells within them, and these germ-cells give rise to little **cercaria** which look something like tiny tadpoles. These tadpole-like cercaria leave the snail and swim to the shore to form cysts on surrounding vegetation.

As the sheep pass along and eat the vegetation bearing these cysts, the life-cycle is again begun. It will be noted from the account just given that the larval stages breed in cold-blooded animals, while the adult stages must have warm-blooded animals for their hosts.

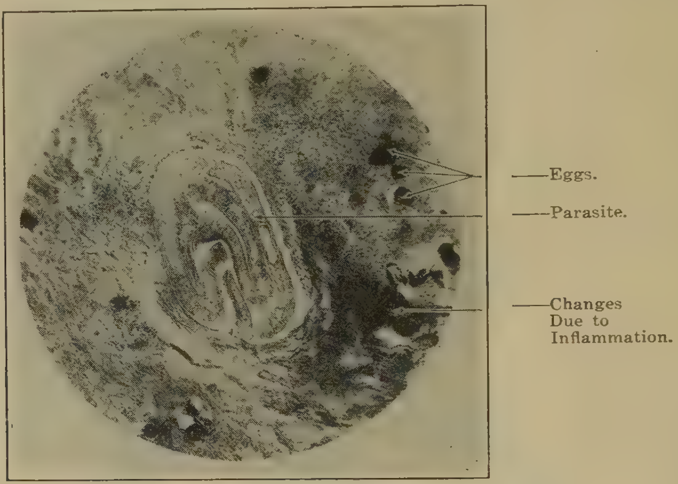


Fig. 180. *Schistosomum Haematobium.*
(*Distoma Haematobium.*)
From the submucosa of the large intestine of man.
(From a photograph lent to the author by
Dr. E. L. Miloslavich.)

The liver fluke is by no means unknown to affect the human liver, and where this is known to be the case, great care must be exercised in eating uncooked vegetables.

From the complicated life-cycle the liver fluke displays, it can readily be understood that many thousands of eggs must be produced by a single animal if liver flukes are not to die out; for, it is not at all likely that many of the miracidia will find a snail host; and then again, it is not very likely that many of the cysts on the shore vegetation will be eaten by sheep.

One liver fluke will produce as high as five hundred thousand eggs, and a single sheep may contain over two hundred adult flukes. This means that over a hundred millions of eggs may develop in a single sheep.

Trematode Infections.

Schistosomum haematobium (Fig. 180), (also called **Bilharzia haematobia**), which causes the disease known as **bilharziosis**, is by no means uncommon in tropical countries such as Asia and Africa, and is sometimes found in Europe and America.

The mature worm lives in the branches of the portal veins so that the eggs are easily distributed (with the blood) into the liver and other organs of the body. The eggs, which are the true cause of the disease, have a tendency to affect the urinary apparatus, causing a bloody urine to be discharged and also causing destructive and over-growth processes in the bladder, urethra, and surrounding parts. All these infected parts are loaded with eggs so that abscesses and fistulas form. Similar conditions may take place in the rectum. Ten per cent of all patients in Cairo were found to be infected, while seven and a half per cent of all army recruits in Egypt showed the eggs in their urine.

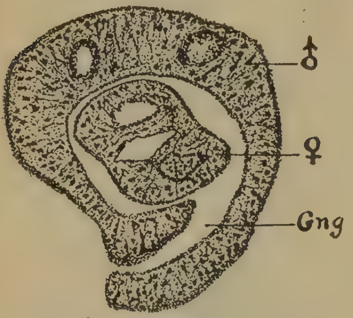


Fig. 181. Schistosoma Japonicum. ♂, male, containing the female, ♀, in the gynaecophorous groove, *gng*. (After Rivas.)

Schistosomum Japonicum is the Japanese **species.**

This blood-fluke is peculiar in that it has separate sexes, the male being carried about by the female in a **gynaecophorous canal** (Fig. 181).

The eggs are oval and a **terminal spine** is found at one end. The eggs hatch in water, so they may be taken in with raw vegetables or even with drinking water.

It is an interesting fact that **animal parasites often cause no pain,** but are on that very account the more dangerous because the patient infected pays no attention to his infection and the disease thus grows constantly worse without any attention being given it.

Schistosoma japonicum vel cattoi. This species is common in China, Japan, and the Philippines. The disease produced by it is called **Katayama disease.** The liver hardens and the spleen enlarges. There is dysentery and a loss of blood.

The eggs are smaller than **S. haematobium** and they do not have the terminal spine.

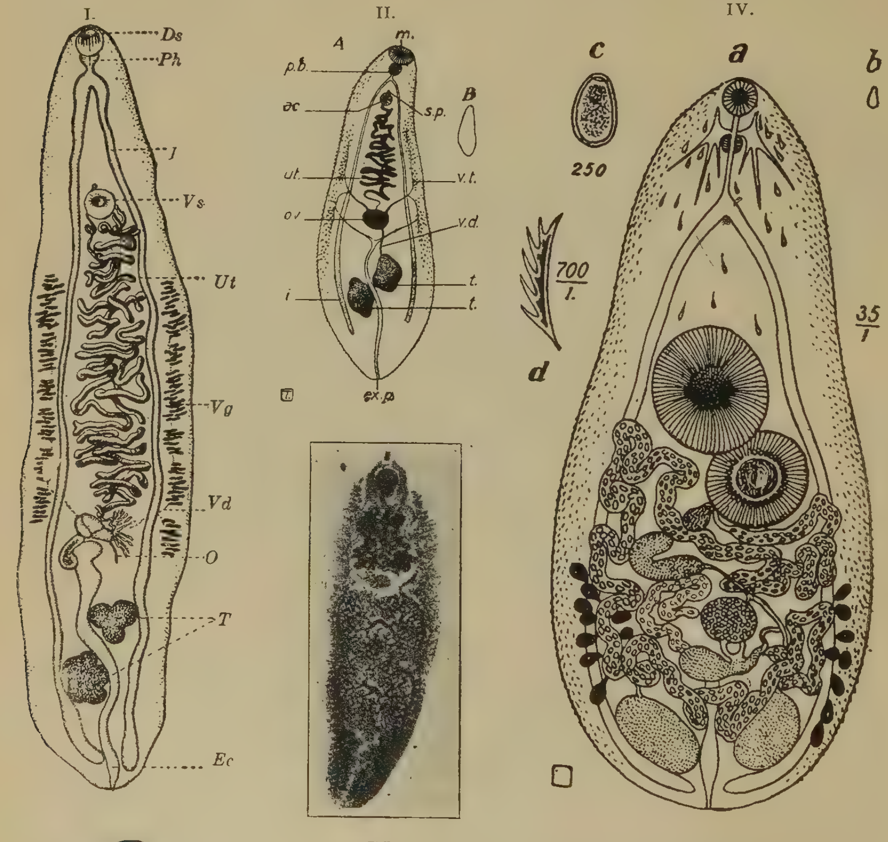
In Formosa, **Paragonimus Westermani** (Fig. 182), (Asiatic lung-fluke or bronchial fluke), is often found as a parasite infecting the lungs of man. It is also found in the brain where it causes death from pressure.

The worm is 8-16 mm. long and 4-8 mm. broad, and is pinkish or red in color. The disease it causes is often confused with tuberculosis, although the microscope shows many eggs in the sputum. The liver, brain and eyelid are the most common points affected.

The common liver-fluke **Fasciola hepatica**, though rare in this country, is common in Syria where men eat raw goat-livers. The disease is called Halzoun.

Opisthorchis (Distoma) felineus is common in cats. It has been found in Prussia, Siberia, and Nebraska.

Opisthorchis noverca (Distomum conjunctum) is the Indian liver-fluke.



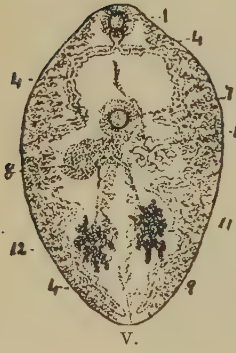


Fig. 182. Infective Trematodes.

I. *Opisthorchis felineus*. *Os.*, oral sucker; *Ph.*, pharynx; *I.*, intestine; *Vs.*, ventral sucker; *Ut.*, uterus; *Vg.*, vitelline glands; *Vd.*, vitelline duct; *O.*, ovary; *T.*, testes; *Ec.*, excretory canal.

II. *Opisthorchis noverca*. *A.*, greatly enlarged. *B.*, almost natural size. *m.*, mouth (oral sucker); *ph.*, pharynx; *ac.*, acetabulum (ventral sucker); *ut.*, uterus; *vt.*, vitelline glands; *ov.*, ovary; *vd.*, vas deferens; *t.*, testes; *i.*, intestine; *exp.*, excretory pore.
III. *Fasciolopsis buski.*

IV. *Heterophyes heterophyes*. *a.*, schematic and highly enlarged; *b.*, about twice natural size; *e.*, eggs, greatly magnified; *d.*, spine greatly magnified. (I, after Stiles and Hassal; II, after Manson; III, after Rivas; IV, after Loose.)

V. *Paragonimus Westermani* (Asiatic Lung Fluke): 1, oral sucker; 4, intestine; 7, acetabulum; 8, ovary; 9, excretory canal; 11, yolkglands; 12, testis; 14, uterus. (After Pratt.)

Opisthorchis (Distoma) sinensis. This is one of the most important of liver-flukes. It occurs extensively in Japan, China and India. It is 10-20 mm. long and 2-5 mm. broad. The eggs are oval and dark-brown with sharply defined operculum. **O. sinensis** are also found in Canada and the United States. Children are usually affected, and whole villages succumb to its ravages.

Fasciolopsis (Distoma) buski is common in India, and
Mesogonimus heterophyes in Egypt and Japan.

CESTODA

The common tapeworm, **Taenia solium** (Fig. 183) is the best laboratory example of **Cestoda.** It lives in the digestive tract of man and feeds upon the already digested food of its host. The tapeworm therefore needs no digestive system of its own, and it has none.

Taenia is a long flatworm consisting of a knob-like head called the **scolex,** and a great number of segments which are all like each other but different from the scolex. These segments are known as **proglottids.**

Hooks and **suckers** on the scolex permit the animal to fasten itself to the walls of the digestive tract of its host. A small constriction between head and proglottids is called the neck. The proglottids usually increase in size the further they are from the scolex. It is not uncommon to have a tapeworm reach ten or more feet in length and have some eight or nine hundred proglottids. The proglottids are budded off from the neck, so that the segments furthest from the head are the older. The process of forming new proglottids is called **strobilization.**

The body of the simplest type of tapeworm is not segmented, though most forms are.

Each proglottid contains a set of both male and female reproductive organs, but the nervous and excretory systems are usually quite continuous through head and proglottids. The question often arises as to whether each segment is not a complete individual, but the best authorities believe that the scolex is an asexual individual which buds off the sexual individuals which we have called proglottids.

There are a good many species of tapeworms, but all of them live as parasites in the intestinal tract of other animals, and nearly all of them require two hosts before their life cycle is completed. And, just as the liver flukes require a cold-blooded and a warm-blooded animal as their hosts, so the tapeworms usually require some herbivorous animal as a host for the larval stages, and an animal which eats the flesh of the herbivorous animal for the adult stages. We therefore have tapeworms using pig and man, cow and man, fish and man, mealworm and rat, fleas and dog, rabbit and wolf, etc., as the two hosts.

An adult tapeworm in the intestine of man will continually develop new proglottids which pass out of the body and shed the eggs upon the ground. Each proglottid may produce thousands of eggs. If these eggs

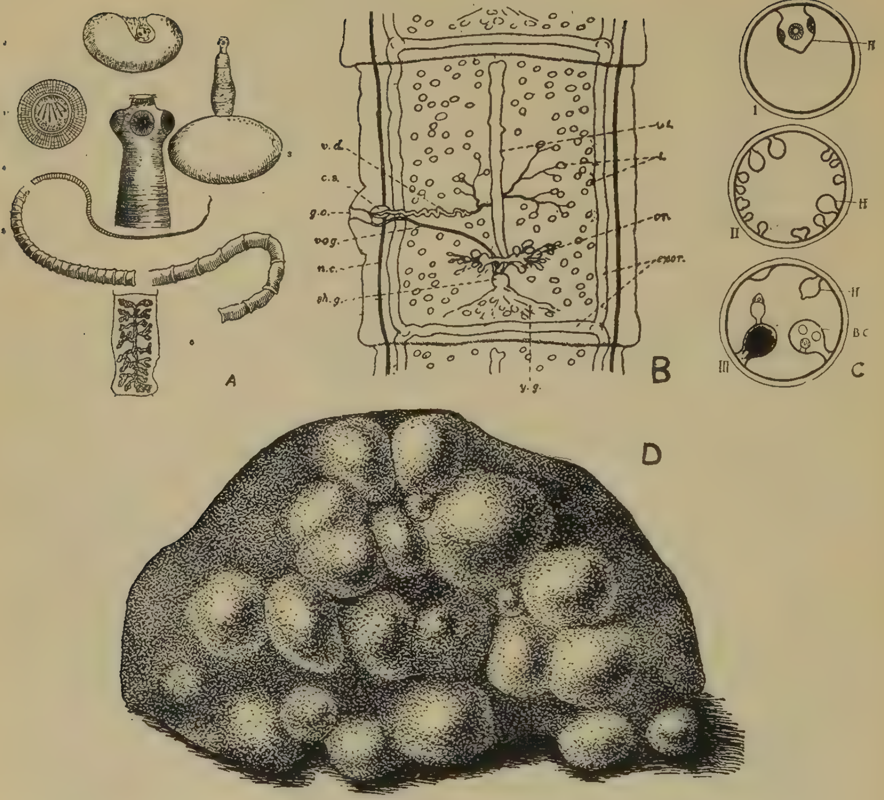


Fig. 183. Tapeworms.

A. The Life-History of *Tœnia solium.* 1, six-hooked embryo in egg-case; 2, proscolex or bladder-worm stage, with invaginated head; 3, bladder-worm with evaginated head; 4, enlarged head of adult, showing suckers and hooks; 5, general view of the tapeworm, from small head and thin neck to the ripe joints; 6, a ripe joint or proglottis with branched uterus; all other organs are now lost.

B. A proglottis of *Tœnia solium* with the reproductive organs at the stage of complete development. *cs.*, Cirrus sac; *excr.*, excretory canals; *g.o.*, genital opening; *n.c.*, nerve cord; *ov.*, ovary; *sh.g.*, shell gland; *t.*, testes; *v.d.*, vas deferens; *ut.*, uterus; *vag.*, vagina; *y-g.*, yolk gland.

C. Diagrams of Bladder-Worms. I. The ordinary Cysticercus type, with one head. II. The Cœnurus type, with many heads. III. The Echinococcus type, with many heads, and with blood capsules producing many heads.

D. Portion of hog's liver infested with echinococcus bladder-worm. A, after Leuckart; B and C, after Borradaile; D, after Stiles.)

then come in contact with grass, weeds, hay, or any vegetation which cattle eat, they hatch in the intestine of the animal eating such vegetation. Each egg will develop a little six-hooked embryo which leaves the egg and bores its way into the cow's body. It comes to rest either in the liver or muscle tissue.

In about three months a bladder-worm known as a **cysticercus** has developed, and if flesh containing these bladder worms is eaten by man, he is in turn infected.

The cysticercus is really a tiny bladder-like sac with a scolex pushed in on one side. When this gets into man's intestine, the scolex is pushed outward so that it can fasten its hooks into its new host's intestine. It is now ready to bud off proglottids again.

At least one per cent of all cattle slaughtered in this country have tapeworms. Certain species are also found in pork. All meat should therefore be well cooked before eating.

The structure of the tapeworm is quite similar to **Planaria**, the flatworm which served as our introduction to this phylum.

It is well, however, to obtain a good description of the way tapeworms reproduce, as it is due to their reproduction that infection takes place.

The mature proglottid is almost entirely filled with reproductive organs. From the spherical testes (which are scattered throughout the entire proglottid) the sperm cells are carried through the vas deferens, after being gathered into fine tubules, and pass to the genital pore.

Eggs arise in the two-lobed ovary, and pass into the oviduct. Yolk from the yolk-gland then enters the oviduct and surrounds the eggs. After this a shell is provided for the egg by the secretions from the shell-gland, and the eggs pass into the uterus. The eggs have by this time been fertilized and pass into the vagina. As the proglottid grows older, the uterus becomes extended with eggs and even sends off uterine branches likewise filled with eggs, while the rest of the reproductive organs are absorbed. The proglottid is then said to be ripe. When ripening occurs, the proglottid is very likely to break off and be thrown out with the faeces.

Cestode Infections.

There are four principal types of cestode worms (Fig. 184) which infect the human being. These are:

Taenia saginata or **mediocanellata,**
Taenia solium,
Bothriocephalus latus,
Taenia echinococcus.

Each of these requires an intermediate host for the development of the larval forms. The eating of the flesh of the intermediate host releases the larval forms and the mature worm forms in the human host.

Taenia saginata (the **common beef-tapeworm**) is common in the small intestine of man. As the segments (which are loaded with eggs) ripen, they are discharged. The eggs are taken up with the food of the ox. Then the embryo pierces the intestinal wall with the six hooks on the worm's head. As it bores its way through into the blood-stream, this blood-stream carries it throughout the entire system. Finally, they come to rest in various muscles and develop into a **cystic larval form.** It is at this point that man becomes infected if raw beef is eaten which contains these larvae.

Taenia solium has less uterine pouches filled with eggs than

Taenia saginata. These eggs are ingested by pigs. This type of tapeworm is rare in the human intestine in America, although it does occur. The process of development is quite like that of **Taenia saginata.** The cystic larvae of **Taenia solium** are called **Cysticercus cellulosae.**

Bothriocephalus Latus is found in many types of fish, such as salmon, trout, perch, etc., and if this is ingested by man it passes through

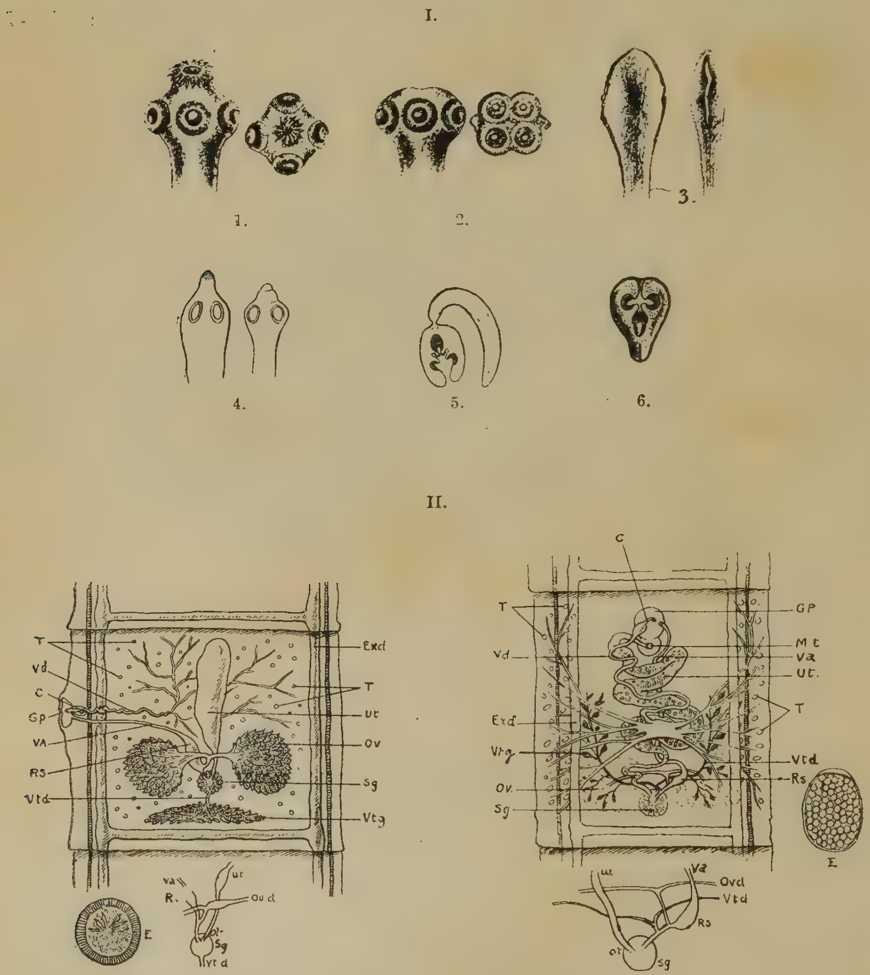


Fig. 184. Types of Cestoda.

I. Heads of 1, *Taenia Solium;* 2, *T. Saginata;* 3, *Dibothriocephalus latus;* 4, *Dipylidium caninum,* this latter showing rostrum both evaginated and invaginated; 5, immature and 6, mature cysticercoid. (From various authors.)

II. Diagram of the anatomy of Tapeworms. 1, *Taenia saginata;* 2, *Dibothriocephalus latus. T,* testes; *Vd.,* vas deferens; *C.,* cirrus; *Gp.,* genital pore; *Va.,* vagina; *Rs.,* receptaculum seminis; *Vtg.,* vitelline glands; *Vtd.,* vitelline duct; *Sg.,* shell gland; *Ov.,* ovaries; *Ovd.,* Oviduct; *Ut.,* uterus; *Ot.,* ootype; *Exd.,* excretory duct; *Mt.,* metraterm. (After Rivas.)

the various stages already mentioned and produces considerable anaemia. The genital openings are on the face of each segment in **Bothriocephalus latus** instead of at the edges as in **Taenia.**

Taenia echinococcus differs from the three forms just mentioned in that man is the intermediate host and the dog the true host

It also differs in size from those mentioned. Tapeworms in the human being may reach a length of thirty to forty feet, but **Taenia echinococcus** is only three mm. to six mm. in length. In cold countries where men and dogs live in the same room and where dogs lick their master's faces, eggs are transmitted to the human digestive tract, although intermediate hosts other than man are possible.

The developing cyst in the instance of the small worm is very large, and there is a closely allied form known as **Taenia multilocularis** which often is present with **Taenia echinococcus,** and when this is the case, a great mass of ramifying spongy tissue, full of small cavities, forms. If these cysts grow in the brain the sheer pressure of the cysts cause injury and then, too, if the first cyst ruptures it pours out poisons in the system, as well as again spreading new larvae which form secondary cysts.

The eggs, when in the human intestine, hatch and bore through the intestinal wall and are swept along by the blood-stream to their lodging place. A thin, pearl-colored covering then surrounds it and about this the tissues of the host react so as to form a capsule. A liquid is formed in the thin membrane while buds grow out of the membrane. These buds are finally recognizable as the heads of new worms. The heads turn inside out, causing the hooks to face inward. This makes it possible for the worm to be swallowed by dogs and pigs. Then the head turns back again to make use of its hooks and suckers. If no intermediate host is found, the worms may die, but in such a case there is a large cyst filled with a mortar-like white material remaining.

Following is a summary of all the important
Tapeworms and their hosts:

Name	Final Host	Intermediate Host
Taenia solium	Man	Hog (in liver, muscles, brain and eye).
Taenia saginata	Man	Ox and Giraffe (in muscles).
Taenia elliptica **Taenia cucumerina** (Both of these are also called **Dipylidium caninum**	Dog and cat mostly, but also man	In body-cavity of dog, fleas and lice.
Taenia flavo-punctata	Common in rats	Moths and beetles.

(Hymenolepsis diminuta).	Twelve cases known in man.	
Taenia nana .... **(Hymenolepsis nana)** ...	Common in Italy and known in America.	
Taenia confusa	A few cases in Man.	
Dibothriocephalus latus..	Man and Dog ..... Common in Finland and regions where fish is a common food.	In peritoneum and muscles of pike, perch, and trout.
Drepanidotaenia setigera.	Goose	Water-flea and Cyclops brevicaudatus.

THE THREAD-WORMS

NEMATODA

The nematodes are the thread-worms or round worms which make up the phylum **Nemathelminthes.**

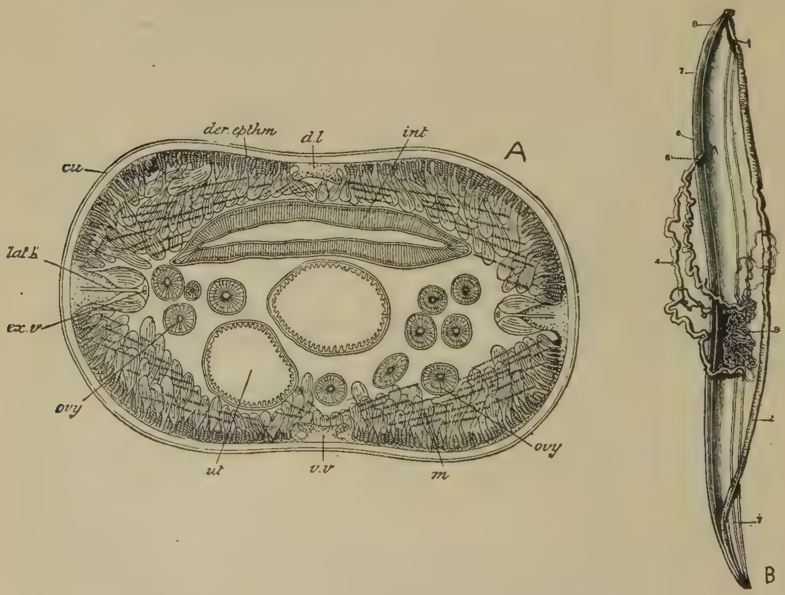


Fig. 185. A Cross Section, *Ascaris Lumbricoides.*

A, Transverse section. *cu.*, cuticle; *dl.*, dorsal line; *der. epthm.*, epidermis; *ex.v.*, excretory tube; *int.*, intestine; *lat. l.*, lateral line; *m.*, muscular layer; *ovy.*, ovary; *ut.*, uterus; *v.v.*, ventral line.

B. A female cut open to show internal structures. 1, pharynx; 2, intestine; 3, ovary; 4, uterus, 5, vagina; 6, genital pore; 7, excretory tube; 8, excretory pore. (A, after Vogt and Yung; B, after Shipley and MacBride.)

This phylum is likely to prove confusing to students as there are various systematists who classify thread-worms under different phyla and under groups which they call **uncertain.**

Nematodes form the single class of **Nemathelminthes,** and the two best known forms used in the laboratory are **Ascaris lumbricoides** (Figs. 185 and 186), a parasitic worm found in the digestive tract of pigs, horses, and man, belonging to the family **Ascaridae**; and **Trichinella spiralis** (Fig. 187), of the family **Trichinellidae,** which causes a very dangerous disease called **trichinosis** in rats, pigs, and man.

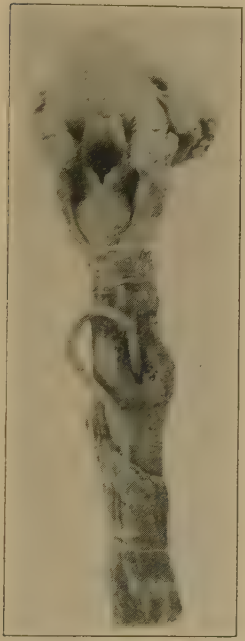


Fig. 186. Tuberculous Cavity in Oesophageal Wall of Man Containing an *Ascaris Lumbricoides.* (From a photograph lent the author by Dr. E. L. Miloslavich.)

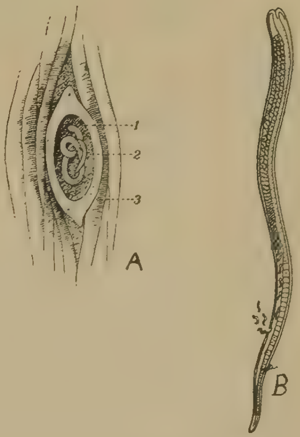


Fig. 187. *Trichinella Spiralis.*
A. Encysted Trichina Embryo.
B. Adult female from Intestinal wall. 1, parasite; 2, membrane of cyst; 3, muscle-fiber of pig. (After Leuckart.)

The female **Ascaris** is the larger of the sexes; in fact, it may grow to a length of from five to eleven inches and a fourth of an inch in diameter. The body is of a light brown color with a narrow white stripe along the dorsal and ventral surface, and a broader white line lying on each side of the dorsal and ventral stripe.

The mouth-opening (which is surrounded by one dorsal and two ventral lips) lies at the anterior end of the animal. The anal opening lies at the posterior end. The tail-end of the female is straight, while in the male it is slightly bent. In the male also there are **penial setae,** which extend through the anal opening and which are used for copulation.

The Digestive System.

The digestive system is very simple, consisting of a mere straight tube into which the already digested food of the host enters. A definite coelom may also be seen. The more anterior portion of the digestive tube is known as the **pharynx.** This is muscular, so that by contraction and expansion it can draw the host's food into itself. At the posterior end of the digestive tube the intestine becomes smaller. This is the **rectum,** which empties through the anal opening.

The Excretory System.

This system consists of two longitudinal canals, one being located in each lateral line. These open through a single pore near the anterior end of the ventral body-wall.

The Nervous System.

A definite ring of nervous tissue surrounds the pharynx. From this ring a dorsal and a ventral nerve cord are given off, as well as a number of fine nerve strands and connections.

The Reproductive System.

In the male there is but a single testis, which is coiled and threadlike. The sperm cells pass from this through a **vas deferens** to a **seminal vesicle** and from here through the ejaculatory duct to the rectum.

In the female the reproductive system is Y shaped, the two arms of the Y being the coiled ovaries which are continuous with the uterus. It is the two uteri which unite in the stem of the Y to form a muscular tube, the **vagina,** which opens to the outside of the body by a **genital aperture.**

The egg is fertilized in the uterus, after which a chitinous shell surrounds it, and the egg is then thrown out through the genital pore. It is this chitinous shell which prevents the egg being digested in the intestine of the host where it must necessarily fall when being laid.

As nematodes are triploblastic animals with three definite germ layers, these animals also have a **coelom.** Consequently, the body of these worms must be thought of as a **tube within a tube,** with the reproductive system lying between digestive tract and the body wall—that is, within the coelom.

However, the coelom is quite different in worms from what it is in higher animals.

In the higher forms, the coelom is **a cavity between the two layers of mesoderm.** The excretory organs open into it and from its walls the reproductive cells originate. In **Ascaris** the coelom has only the meso-

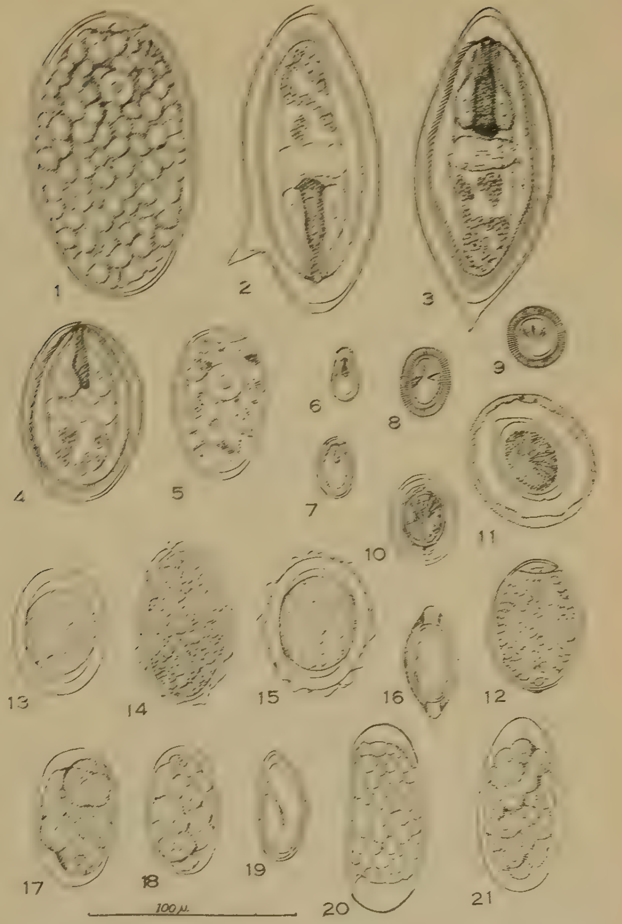


Fig. 189. Eggs of the More Important Worms Which Are Parasitic to Man.

As all are of the same magnification, a comparison of the relative sizes is possible.

1, *Fasciolopsis buskii;* 2, *Schistosoma mansoni;* 3, *Schistosoma haematobium;* 4, *Schistosoma japonicum;* 5, *Paragonimus westermanii;* 6, *Clonorchis sinensis;* 7, *Metagonimus yokogawai;* 8, *Taenia saginata;* 9, *Taenia solium;* 10. *Hymenolepsis nana;* 11, *Hymenolepsis diminuta;* 12, *Diphyllobothrium latum (Dibothriocephalus latus);* 13, *Ascaris lumbricoides* (egg without outer coating); 14, *Ascaris lumbricoides* (abnormal egg); 15, *Ascaris lumbricoides;* 16. *Trichuris trichiura;* 17 and 18, *Hookworm eggs;* 19, *Enterobius vermicularis oxyuris vermicularis;* 20, *Oxyuris incognita;* 21, *Trichostrongylus orientalis.* (After Hegner and Cort's "Diagnosis of Protozoa and Worms Parasitic to Man." Bull. Johns Hopkins University school of Hygiene and Public Health.)

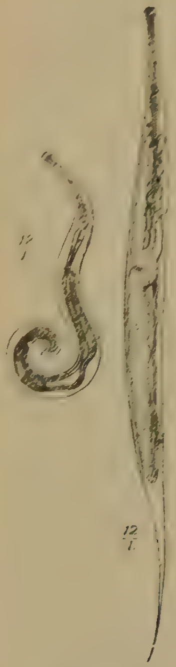


Fig. 188.
Oxyuris Vermicularis
The male is on the left, the female on the right.
(After Claus.)

derm of the body wall as a lining. There is no mesodermal lining surrounding the intestines. Then, too, the excretory organs open directly to the outside through the excretory pore, and the reproductive cells do not originate from the epithelium of the coelom. Notwithstanding this difference, the space between intestinal tract and body wall is called a coelom in worms.

Nematode Infections (Figs. 185, 186, 187, 188).

Ascaris lumbricoides is found chiefly in children. The female is from seven to twelve inches in length and the male from four to eight inches. The worm is pointed at both ends and of a yellowish-brown or slightly reddish color. There is no intermediate host. The animal occupies the upper portion of the small intestine. Usually one or two are found in a single location, although sometimes vast numbers of them may be found. The worm may pass to the stomach and be vomited forth, or it may crawl up the oesophagus and then pass into the larynx and asphyxiate the patient. In fact, it may enter any ducts or tubes in the body.

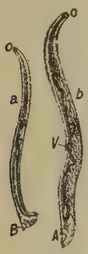


Fig. 190. The Hookworm. *a.*, male; *b.*, female; *o.*, mouth; *V.*, opening for discharge of eggs. (After Leuckart.)

Oxyuris vermicularis (commonly called **pin-worms** or **thread-worms**), (Fig. 188), are parasites of the rectum and colon. The male is about 4 mm. long and the female about 10 mm. The parasites migrate and come close to the surface during the night, thus causing accentuated irritation and itching about the rectum and genital organs. Many eggs are found in the faeces of infected children. It is essential that the distinguishing and diagnostic difference between **oxyuris eggs** and **trichocephalus** eggs be known. Both types are quite alike except that **trichocephalus** eggs have a button-like lighter area (Fig. 189, 16). Re-infection must be guarded against. These worms often find their way into the appendix of children where they drill into the mucous membrane and cause appendicitis. **Trichina** (Fig. 187), (also called **Trichinella spiralis**), lives in the small intestine when adult. The disease **trichiniasis** is caused by the embryos after they pass from the intestines to the voluntary muscles where they encapsulate themselves as larvae.

The female is 3 to 4 mm. long and the male 1.5 mm. There are two tiny projections from the posterior end of the worm. The larvae, when encased in the muscle, is about 1 mm. long. **Trichina** have a pointed head and a somewhat rounded tail. The parasites are ingested by man when eating inadequately cooked pork. Each worm may produce as high as 10,000 young, which are either placed directly into the lymphatics by the female or burrow through the intestinal wall. They then encyst in the muscle tissue. Pigs acquire the disease by eating offal or infected rats.

Twenty-six different kinds of animals have been found in which trichinae grow, and as many as 15,000 of these parasites have been found in one gram of muscle.

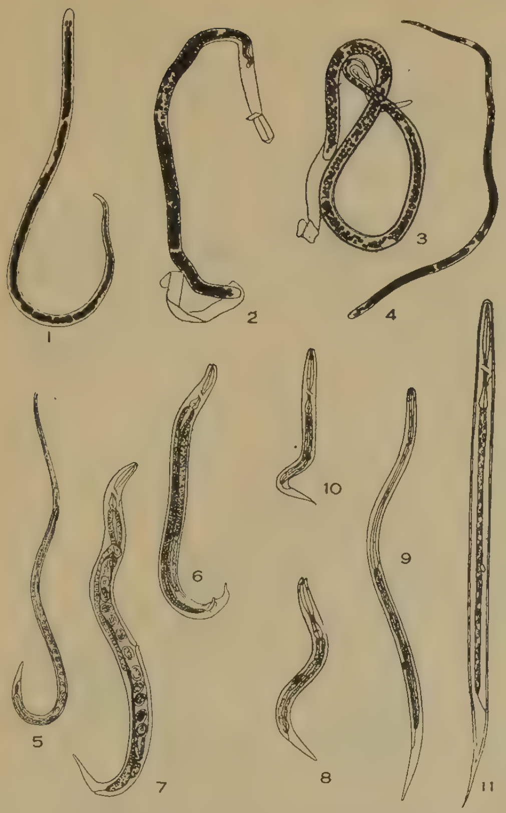


Fig. 191. Forms of Worms Parasitic to Man.

1. Larval stage of *Filaria ozzardi* (F. demarquayi).
2. Larval stage of *Loa loa* (*Microfilaria diurna*).
3. Larval stage of *Filaria bancrofti* (*Microfilaria nocturna*).
4. Larval stage of *Acanthocheilonema perstans* (*Microfilaria perstans*).
5. Adult parasite female of *Strongyloides stercoralis*.

6 and 7. Adults, male and female, of the free-living generation of *Strongyloides stercolaris*.

8. Rhabditiform larva of *Strongyloides stercoralis*, just hatched from egg.
9. Filariform infective larva of *Strongyloides stercoralis*.
10. Rhabditiform larva of *Ancylostoma duodenale*, just hatched from the egg.
11. Filariform infective larva of *Ancylostoma duodenale*. (From Hegner and Cort's "Diagnosis of Protozoa and Worms Parasitic to Man"; 1-4, after Fulleborn; 5-11, after Looss.)

It may take about six weeks for complete encapsulation, but once encapsulated they may remain alive for twenty or twenty-five years in the muscle.

Pigs may be literally "filled" with these parasites, causing what is known as "measly pork," although they may show no external sign of infection. Many countries now insist on pork inspection to prevent a spread of infection.

The patient usually suffers with a fever, anaemia, muscle pains **(myositis)**, which are often mistaken for rheumatism, and intestinal disturbances (gastroenteritis).

Ankylostoma duodenale in the old world, and **Necator americanus** in this country are the **Hook-worms** (Fig. 190). The disease caused by hook-worm is variously known as ankylostomiasis, uncinariasis, hook-worm disease, tropical or Egyptian chlorosis, and anaemia of bricklayers and tunnel-workers.

The old-world animal is small and cylindrical, the male being about 10 mm. in length and the female from 10 to 18 mm. There are chitinous plates about the mouth and there are two pairs of sharp, hook-shaped teeth with which the mucosa of the intestine is pierced. On the male there is a prominent caudal, umbrella-like expansion. The American species is slightly more slender, with a globular mouth and a different arrangement of teeth. The eggs of the American form are slightly larger than those of the European forms.

The larvae of the hook-worm develop in moist earth and dig their way through the soles of the feet of persons who go barefoot. Once in the blood-stream they are carried along by it to the heart, thence to the lungs, and many lodge in the windpipe from whence they are swallowed, thus reaching the stomach and intestines. The larval forms here attach themselves to the intestinal walls and feed on the blood of their host. But as they puncture the intestinal wall, they exude a small amount of poison which prevents the host's blood from coagulating. There is thus a constant loss of tiny droplets of blood and the patient naturally becomes anaemic. Not only do persons infected with hook-worm suffer from such loss of blood, but the parasites injure the lungs in passing through them, and thus make tuberculosis infections easy.

The writer was recently told by a worker in the medical corps of the army that more than 75 per cent of the examined southern negroes showed hook-worm infection.

It is of great importance to dispose of all human faeces in rural districts, in mines, brick-yards, etc., so that the soil will not become polluted. This will kill the eggs and thus prevent hatching of the parasites. Strong sunlight seems to be quite effective in doing this also.

The family **Filariidae** is also important from a pathological point of view.

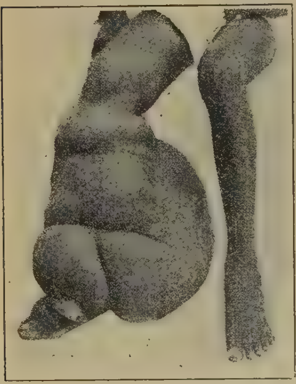


Fig. 192. Elephantiasis in Man: (From "New Sydenham Society's Atlas.")

Filaria bancrofti (Fig. 191) is a parasite in human blood. It is interesting to know that these parasites live in the lungs and larger arteries throughout the day and in the blood-vessels in the skin at night. Mosquitoes, which are active at night, suck the blood of infected persons and thus carry the infection. In fact, it was the knowledge of this which led to the discovery of the malarial parasite's life-cycle.

As the organism is placed in another person by the mosquito, after the larvae have developed in that mosquito's body, they enter the lymphatics and cause serious difficulties, probably by blocking the lymph passage. If there is such a blocking, **elephantiasis** results. This is a practically incurable disease in which the limbs or other portions of the body swell to an enormous size, although producing little or no pain. (Fig. 192.) In certain portions of the South Sea Islands almost a third of the population is affected.

Medical men speak of **Filaria diurna** and **Filaria perstans.** The first of these differs from **F. bancrofti** in not having granules in the axis of the body, and the second by having its embryos smaller (namely, about 200 microns) than the preceding. Only the embryos have been seen. The embryos of **F. Bancrofti** are about 270 to 340 microns in length. The adult is about 83 mm. long and the female some 155 mm. The tail

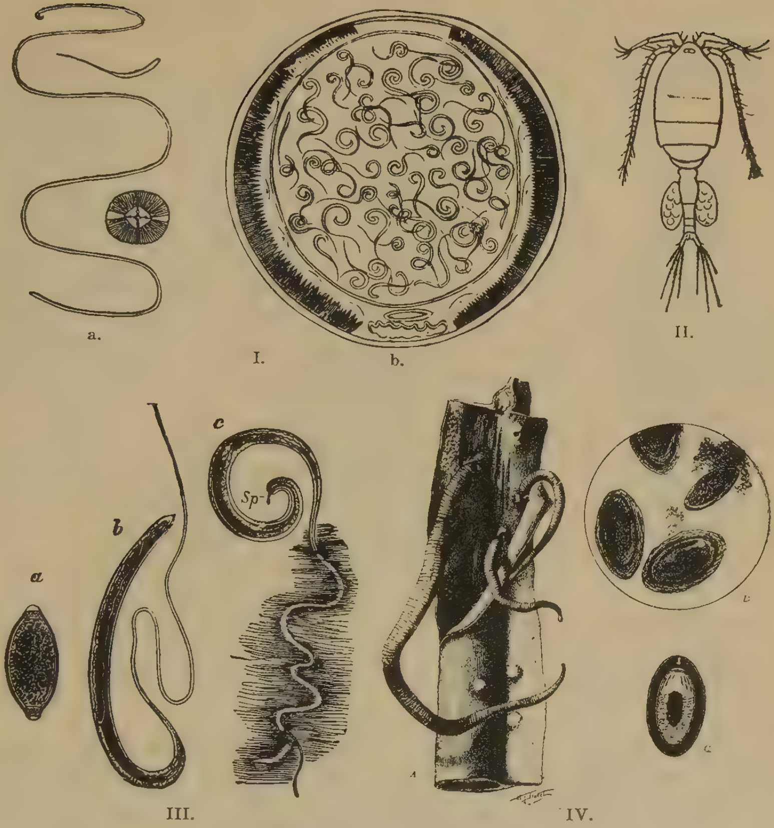


Fig. 193. Other Nematode Parasites.

I. *a.*, *Dracunculus* (*filaria*) *medinensis* (female), showing mouth and embryo. *b.*, Transverse section through adult female of I, *a*, showing many embryos in the uterus.

II. *Cyclops.* This animal is the intermediate host of *Dracunculus.*

III. *Trichocephalus dispar* (also called *Trichuris trichiura*) of the Family *Trichinellidae.* *a.*, egg; *b.*, female; *c.*, male attached to the intestine, showing the long, slender, cephalic end buried in the submucosa; *sp.*, spicule.

IV. *Gigantorhynchus gigas*, of the Class *Acanthocephala*, and Family *Echinorhynchidae.* *A.*, two males and one female adult attached to the mucosa of the intestine; *B.*, eggs as seen in preparation; *C.*, eggs as found in feces. (I, after Bastian and Leuckart; II, after Riley and Johannsen; III, after Leuckart; IV, after Brumpt and Perrier.)

in the male has two spiral turns. The female produces vast numbers of young which enter the blood-stream through the lymphatics. Each embryo is enclosed in a tiny shell about one-ninetieth of an inch in length. They can thus pass through the capillaries quite readily. They can be seen in a blood-drop under the microscope. As many as 2,100 embryos have been seen in 1 cc. of blood.

Dracunculus medinensis is a peculiar worm, the female being about a yard long. It is probably taken in with food. It makes its way downward, and, when arriving at the ankle, usually pushes its head through the skin, causing an abscess. As the eggs are then deposited, it leaves the infected person of its own accord. Few of these have been found in America.

Trichocephalus dispar (Fig. 193), or **whip-worm,** is found in the caecum and large intestine of man. It is 4 to 5 cm. in length, the male being a trifle shorter than the female. The parasite is remarkable in that there is a great differentiation between the two ends of the body. The anterior end, which forms about three-fifths of the body, is very thin and hair-like, while the posterior portion is thick, and, in the female, conical and pointed. In the male it is blunter and rolled like a spring. The eggs are lemon-shaped, 0.05 mm. in length. Each has a button-like projection. There may be as many as a thousand parasites in one person. The parasite produces no known symptoms in the patient, although patients who have been infected have become anaemic and suffered with diarrhoea.

Dicotophyme renale, the male of which is over a foot long and the female over three feet. These are seldom met with, but when present may destroy the entire kidney.

Anguillula aceti or (vinegar eel) has been found in the urine of man, although it is supposed to have been in the bottle in which the urine was collected.

Strongyloides intestinalis is found in the small intestines of man in the tropics. Three per cent of the medical patients of the Isthmus of Panama were found to be infected, and 20 to 30 per cent of the insane division.

Acanthocephalus (thorn-headed worms) are also called **Gigantorhynchus** or **Echinorhynchus.** These are quite common in the intestine of the hog, where they attach themselves by means of a protrusible proboscis covered with hooks. In the old world the larva develops in cockroach grubs, while in America the larva devlops in the June bug.

The **Acanthocephalia** are distinguished from the **Nematodes** and the **Nematomorpha** by the presence of a proboscis and the absence of an alimentary canal.

INTERMEDIATE AND UNCERTAIN FORMS

In addition to the rather definite groups of worms mentioned in this book, there are also various forms of uncertain position.

The term **Mesozoa** (Fig. 194)—(Gr. **mesos,** middle—**zoon,** animal)—is often used as a general grouping for the three following families of parasites: (1) **Dicyemidae,** (2) **Orthonectidae,** (3) **Heterocyemidae.**

They are called **Mesozoa** because they are regarded as intermediate forms between the protozoa and the metazoa. They are closely allied to the flat worms.

The Nemertinae (Gr. **nemertes,** true), are usually placed with the flat worms. They may reach a length of ninety feet and are mostly marine, though a few live in fresh water and in moist earth.

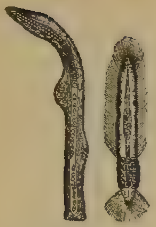


Fig. 194.
A. A Mesozoon, *Dicyema Paradoxum.* (From Parker and Haswell, after Kölliker.)
B. A Mesozoon, *Rhopalura giardii,* male. (From Sedgwick, After v. Beneden.)

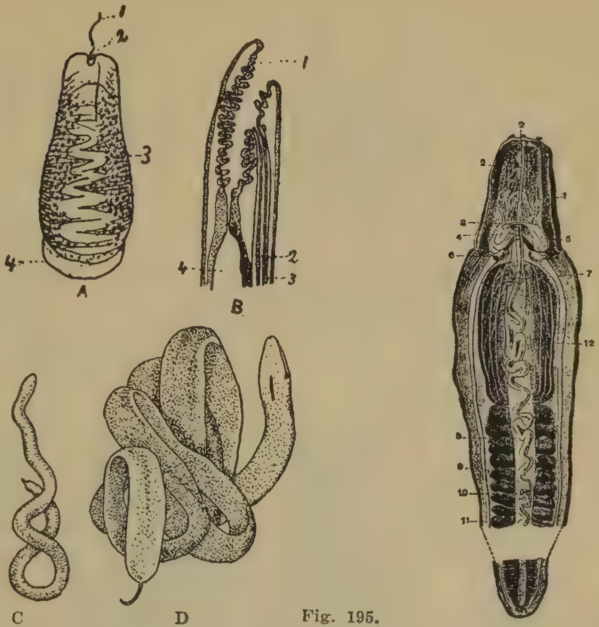


Fig. 195.

A. *Malacobdella grossa* (Verrill), entire worm. 1, proboscis; 2, mouth; 3, intestine; 4, sucker.
B. Section through forward end. 1, mouth; 2, proboscis; 3, proboscis sheath.
C. *Micrura leidy,* (Verrill.)
D. *Cerebratulus lacteus* (Verrill). (From Pratt's "Manual" by permission of A. C. McClurg & Co.)

E. *Cerebratulus fuscus,* a Nemertine. 1, cephalic slits; 2, opening leading into retracted proboscis; 3. dorsal commissure of nervous system; 4, ventral commissure; 5, brain; 6, posterior lobe of brain; 7, mouth; 8, proboscis; 9, lateral vessel; 10, proboscis; 11, pouches of alimentary canal; 12, stomach. (From Shipley and MacBride, after Bürger.)

Cerebratulus (   ), and **Micrura** (   ), (Fig. 195), are the usual examples of marine **Nemertinae.** Other forms are not common. **Malacobdella** (   ) is parasitic in some mollusks.

The Nemertinae are considered **the lowest form of animal life** in which the **blood-vascular system appears.** There is a definite mesoderm and a nervous and an excretory system quite like those in flatworms, but they all have a long proboscis just above the digestive tract which lies within a sheath. This can be everted. The body is covered with cilia. These animals feed on other animals both dead and alive. They usually live in burrows of mud and sand, though **Cerebratulus** is free swimming.

A peculiar larval stage known as the **Pilidium** (Fig. 198 D) resembling a helmet with cilia and a long tuft at the apex, is a distinguishing feature of the development of **Nemertinae.** Ectodermal invaginations surround the alimentary tract of the **Pilidium.** This invaginated portion escapes from the larval form and becomes an adult.

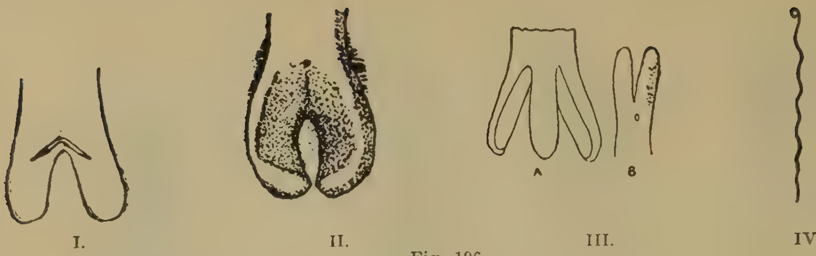
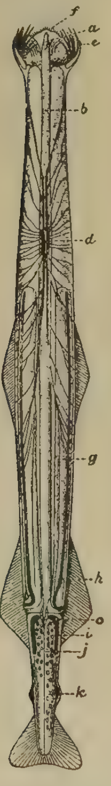
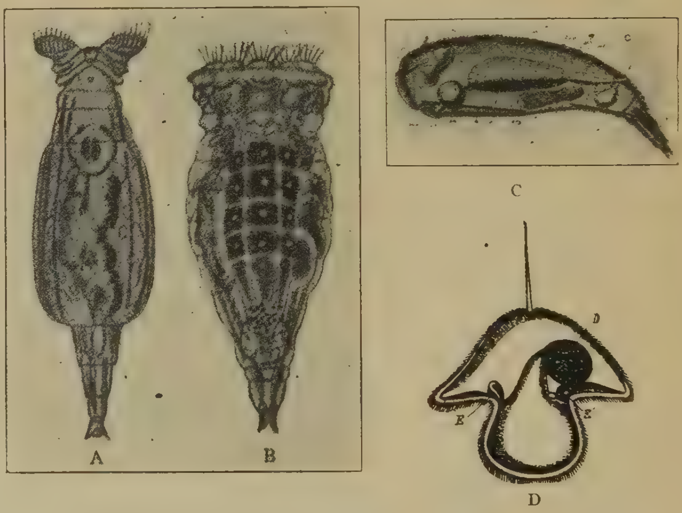


Fig. 196.

1. *Gordius aquaticus;* hinder end of male.
II. *Gordius lineatus;* hinder end of male.
III. *Paragordius varius*; A, hinder end of female; B, of male.
IV. *Nectonema agile;* (From Pratt's "Manual" by permission of A. C. McClurg & Co.)





A. B. Two species of Rotifera. A, Philodina. B, Hydatina. (From Parker and Haswell, after Hudson and Gosse.)

C. Diagram showing the anatomy of a Rotifer. *a*, anus; *br*, brain; c^1, preoral, and c^2, postoral circlet of cilia; *c.gl*, cement gland; *cl*, cloaca; *d.ep*, dermic epithelium; *d.f*, dorsal feeler; *e*, eye; *fl.c*, flame-cells; *int*, intestine; *m*, muscles; *mth*, mouth; *nph*, nephridial tube; *ov*, ovum; *ovd*, oviduct; *ovy*, germarium; *ph*, pharynx; *st*, stomach; *vt*, vitellarium. (From Parker and Haswell.)

D. *Pilidium* larva of a Nemertine. *D*, alimentary canal; *E*, *E'*, the two pairs of ectodermal invaginations. (From Sedgwick, after Metschnikoff.)

Fig. 197.
The arrowworm, *Sagitta hexaptera* (of the group Chaetognatha), ventral view. a, mouth; b, intestine; c, anus; d, ventral ganglion; e, movable bristles on the head; f, spines on the head; g, ovary; h, oviduct; i, vas deferens; j, testis; k, seminal vesicle. (After Hertwig).

The **Nematomorpha** (Gr. **nema,** thread—**morphe,** form), is made up of the single family **Gordiidae** (Fig. 196). These are the common **horse-**

hair snakes. Various authors classify them under the order of **Nematoda,** while others classify them under the **Phylum Nemathelminthes.** There are two genera: **Gordius,** which lives in fresh water, and **Nectonema,** a marine form. The internal anatomy is somewhat different from the **Nematodes,** as there is a distinct **epithelium** lining the body cavity and **no lateral lines.** There is also a **pharyngeal nerve-ring,** and a **single ventral nerve-cord,** while the ovaries discharge the eggs **into the body-cavity.** Then, too, the larvae of **Gordius** usually enter immature stages of aquatic insects. These insect larval-forms are then devoured by other animals, and it is in the intestines of the host where they develop until they finally escape into the water.

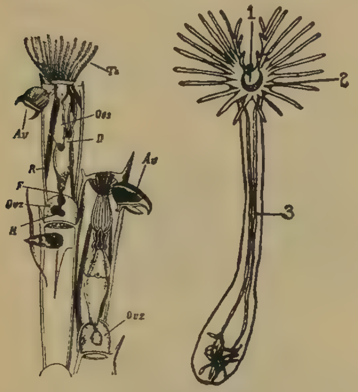


Fig. 199.
A. *Bugula avicularia,* a Bryozoon. *Av,* avicularia; *D,* alimentary canal; *F,* funiculus; *Oes,* œsophagus; *Ovz,* ovicells; *R,* retractor muscle; *Te,* tentacular crown. (From Sedgwick, after V. Nordmann.)
B. *Phoronis architecta.* Young individual with about 30 tentacles. 1, epistome; 2, lophophore; 3, digestive tract. (From Pratt's "Manual" by permission of A. C. McClurg & Co.)

The **Acanthocephala** (Gr. **akantha,** spine—**kephale,** head) are the parasitic worms already mentioned above (Fig. 193), which may infect man. They fasten themselves to the intestinal wall of their host by means of a **protrusible proboscis** covered with hooks. In fact, it is the presence of the proboscis and a reproductive system as well as the absence of an alimentary system which distinguishes the **Acanthocephala** from the **Nematoda** and the **Nematomorpha.** There is an alternation of hosts during the developmental stages.

The **Chaetognatha** (Gr. **chaite,** horse-hair-**gnathos,** jaw) are marine forms swimming about near the surface of the water. The **arrow-worm** (Fig. 197) is the classic example. This is a member of the genus **Sagitta.** The **Chaetognatha** are quite often included under the **Phylum Nemathelminthes.**

The **Rotifera** or **Rotatoria** (Fig. 198), (Lat. **rota,** wheel-**fero,** I carry), are usually called the **wheel-animalcules.** They are very small and were formerly thought to belong to the **Infusoria.** Most of them live in fresh water. A few are parasitic. The sexes are separate. There are summer and winter eggs produced by the female. The former are thin-shelled and develop without fertilization **(parthenogenetically).** The larger eggs produce only females and the small males. The winter eggs are fertilized, have thick shells, and all develop into females. The eggs of most mollusks pass through a larval stage known as a **trochophore** ( ), which looks quite like the helmet-shaped larva described above. Now, **Rotifers** often resemble these **trochophores.**

Consequently, it is thought by some zoologists that they must be closely related to the mollusks. Rotifers have a peculiar ability to secrete a gelatinous envelope about themselves in times of drought, which protects them for great lengths of time and thus prevents them from perishing.

The **Bryozoa** (Gr. **Bryon,** moss—**zoon,** animal) are **moss-animals** (Fig. 199), which practically all live **a colonial life.** They look something like the hydroid form of **Obelia,** but their general structure is quite unlike **Obelia.** Most of them are marine animals, though there are a few types which inhabit fresh water. The **polypide** is the name given to the soft parts which lie within **a coelomic cavity** and which is surrounded by the **zoöecium** (body-wall).

The **lophophore** ( ) is the crown of ciliated tentacles surrounding the mouth. The **alimentary tract, retractor muscle,** and the **funiculus** (a strand of mesodermal-tissue attached to the stomach), are shown in Figure 199. There are **no circulatory or excretory organs.** The eggs develop in the **oöecium,** which is a modified portion of the body-wall.

Bugula is the usual laboratory example. Certain members of a colony develop jaws for protective purposes. Such jaw-possessing members are called **aviculariae.**

Bryozoa are divided into **Ectoprocta** in which the anus **opens outside** the lophophore, and a coelom is present as in **Bugula;** and **Entoprocta,** in which the anal opening lies **within the lophophore,** while the portion which should be a coelom is filled with mesodermal cells. Examples of this type are **Pedicellina** and **Urnatella.**

The **Phoronidea,** named after an ancient king, **Phoronis,** is made up of the single genus **Phoronis.** The animals belonging to this group are worm-like and are enclosed **in membranous** tubes. They live in sand and are supposed to be related to the **Ectoprocta.**

The **Brachiopoda** (Gr. **brachion,** arm—**pous,** foot) are shelled marine animals (Fig. 200), but with the shell **on the dorsal and ventral portions** of the animal, instead of on the sides as with bi-valves. They are usually attached to some object by a **peduncle.** An excellent example is **Lingula,** a very old type, having been found in some of the oldest geological strata, and which differ but little today from their oldest fossil-remains. The **Brachiopoda** are not worm-like in any way, but they have an uncertain position in classification, and so are included here.

The **Gephyrea** (Fig. 201), (Gr. **gephyra,** mound), often classified under the annelids, are now believed by zoologists to be unrelated, but there is even doubt that the various sub-grouping of **Gephyrea** themselves bear any very close relationship.

Three groups are usually noted:

(1) The **Echiuroidea,** in which the adult shows traces of segmentation, a **proboscis,** and a **pair of ventral-hooked-setae and terminal anus.**

There is a larval trochophore stage. They ordinarily live in crevices of rocks.

(2) The **Sipunculoidea,** which are **unsegmented.** They possess **one pair of nephridia,** a **large coelom** and **anal opening on the dorsal surface, near the head-end.** They usually possess tentacles at the anterior end. They live in sand or bore their way into coral rock.

(3) The **Priapuloidea** are also **unsegmented,** having an anterior-mouth surrounded by **chitinous teeth** and **the anal opening in the posterior region.** They live in mud and sand. The head-end usually projects above the surface of the mud in which they lie.

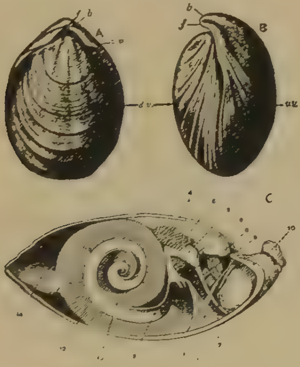


Fig. 200.

Magellania flavescens (of the group Brachiopoda). A, dorsal aspect of shell. B, shell as seen from the left side. *b*, beak; *d.v.*, dorsal valve; *f*, foramen; *v.v.*, ventral valve. (From Weysse, after Davidson.)

Anatomy of a Brachiopod, *Waldheimia australis.* 1, mouth; 2, lophophore; 3, stomach; 4, liver tubes; 5, median ridge on shell; 6, heart; 7, intestine; 8, muscle from dorsal valve of shell to stalk; 9, opening of nephridium; 10, stalk; 11, body-wall; 12, tentacles; 13, coil of lip; 14, terminal tentacles. (From Shipley and MacBride.)

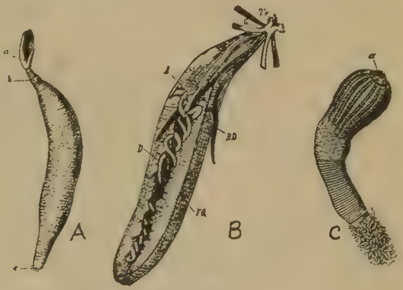


Fig. 201.

A. *Echiurus pallasii* (of the group Gephyrea). *a*, mouth at the end of the grooved proboscis; *b*, ventral hooks; *c*, anus. (From the Cambridge Natural History.)

B. *Sipunculus nudus* (of the group Gephyrea) laid open from the side. *A*, anus; *BD*, brown tubes (nephridia); *D*, intestine; *G*, brain; *Te*, tentacles; *VG*, ventral nerve-cord. (From Sedgwick, after Keferstein.)

C. *Priapulus candatus* (of the group Gephyrea). *a*, mouth surrounded by spines. (From the Cambridge Natural History.)

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CHAPTER XXI.

THE ARTHROPODA

THE CRAYFISH

As an example of a gill-breathing arthropod, the crayfish has become the classic laboratory type, and this because, like the frog, it is already known to the student to some extent.

The phylum to which man and the frog belong—the **Vertebrate**—is in point of numbers much smaller than the phylum **Arthropoda,** to which the crayfish belongs—a group embracing more than three-fourths of all living animals.

The **Arthropoda** are usually divided into **branchiata*** ( ) —commonly called crustacea ( )—those animals possessing a hard **chitinous** ( ) **exoskeleton** and breathing **with gills,** practically all of which live in water; and **tracheata** ( ), consisting of those animals breathing through little tubules called tracheae. The tracheata include **grasshoppers, bees, wasps, ants, spiders,** and **insects** of all kinds. While 400,000 of the 600,000 known species of animals belong to the **Arthropoda,** the greatest sub-group of these is, in turn, the **insects.**

The crayfish is large enough to be studied profitably in the laboratory. All who have lived or spent any of their youth near ponds and rivers, know at least one or two species of crayfish. These they have found lying quietly under the stones in running streams, and when such stones were lifted, the animal's **pincers** were threateningly brought forward to clasp the fingers of the supposed attacker. Then followed a darting backward until the animal again pushed itself under some sheltering object or was able to find some close corner in which its body could be pressed.

The exterior skeleton so prominent in the Arthropoda, is in thorough contrast to that of the frog, whose supporting tissues are placed on the innermost portion of its body; yet it is not from this characteristic that the phylum is named, but from the fact that the animals belonging to this group have jointed legs. The word arthropoda **means jointed feet.**

The crayfish will be used in this book more as a type to introduce nomenclature and general arrangement of the phylum Arthropoda than as a study of detail.

The entry into a more minute investigation of the phylum will come with a study of the grasshopper. The larger and more convenient size

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*This classification into *Branchiata* and *Tracheata* lacks scientific foundation, but is convenient for the beginner and for the student of medicine. As an example of why this classification is not scientific, we may mention the true spiders which have no tracheae and yet are called Tracheates.

of the crayfish serves to show in gross much that is otherwise difficult to observe in the insects and lends itself well to an illustration of **serial Homology** and the so-called **Savigny's law.** The crayfish has not been well studied, then, unless, after completing this chapter, these things are definitely known.

EXTERNAL APPEARANCE

The crayfish is found nearly everywhere in this country and Europe; in the eastern part of the United States **Cambarus affinis** ( ) is prevalent, while **Cambarus virilis** ( ) is more plentiful in the Middle States, and the European specimen found most frequently is the **Astacus fluviatilis** ( ). There is little difference, however, in their external or internal makeup. It will be remembered that the segmentation of the frog is found in the spinal column. With the crayfish, however, segmentation can be observed externally running from anterior to posterior end, though there is a peculiar condition of **fusing** of a number of the anterior segments (Fig. 202) which thus form what is known as the **cephalothorax** ( ).

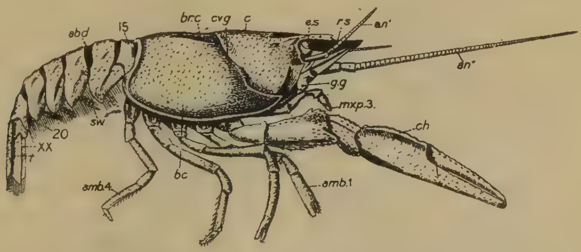


Fig. 202. The common Crayfish, *Astacus fluviatilis*, seen from the side.

abd. Abdomen. *amb.* 1. First walking leg. *amb.* 4. Fourth walking leg. *an'*. First antenna or antennule. *an"*. Second antenna. *bc.* Branchiostegite. *br.c.* Branchiocardiac groove. *c.* Carapace. *ch.* Chela. *cv.g.* Cervical groove. *e.s.* Eye-stalks. *g.g.* Opening of green gland. *mxp.* 3. Third maxillipede. *rs.* Rostrum. *sw.* Swimmerets. *t.* Telson. 15. First segment of abdomen. 20. Last segment of abdomen. xx. The last appendage. (After Shipley & MacBride.)

As one may observe in the embryological study of the crayfish that each embryonic segment possesses a pair of appendages, it is but necessary to count the appendages in an adult arthropod in order to find how many segments have fused in any given region. This is known as **Savigny's Law.**

Beginning at the anterior end of the animal we find the first segment having two pairs of long feelers, the longer ones being the **antennae** and the shorter the **antennules.**

Directly behind these there is a series of **modified appendages** (Figs. 202, 203) directly in front of the large **mandibles.** These cover the mouth itself. Two pair of tiny appendages—the **maxillae**—lie anterior to the mandible, while three pairs of appendages—the **maxillipeds**—lie posterior to it, so modified as to form jaws. The two pair of maxillae and the three pair of maxillipeds, together with the **mandible**, thus make **six pairs of jaws** altogether.

Back of these six jaws, a pair of pincers is attached to the thorax proper. These are known as **chelipeds** ( ), and behind the chelipeds are **four pair of walking legs.** By observing these legs it will be noticed that they are very much akin to the cheale proper in that each has a broad attachment, the **protopodite** ( ),

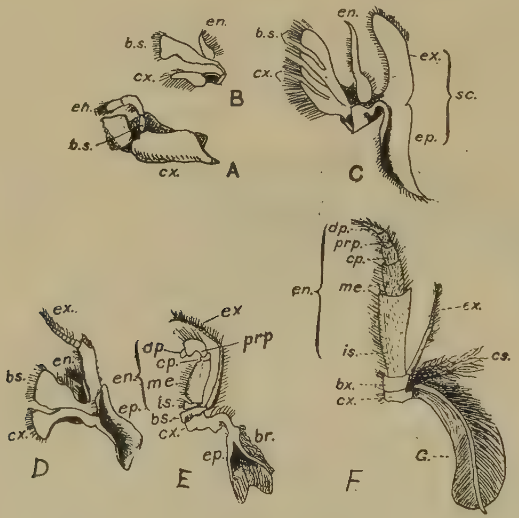


Fig. 203.

A. Mandible. B. First maxilla. C. Second maxilla. *bs.* Basipodite. *cx.* Coxopodite. *en.* Endopodite. *ep.* Epipodite. *ex.* Exopodite. *sc.* Scaphognathite.

D. and E. First and second Maxillipedes. *br.* Branchial filaments. *cp.* Carpopodite. *dp.* Dactylopodite. *is.* Ischiopodite. *me.* Meropodite. *prp.* Propodite portions of endopodite.

F. Third Maxillipede. *cs.* Coxopodite setæ.

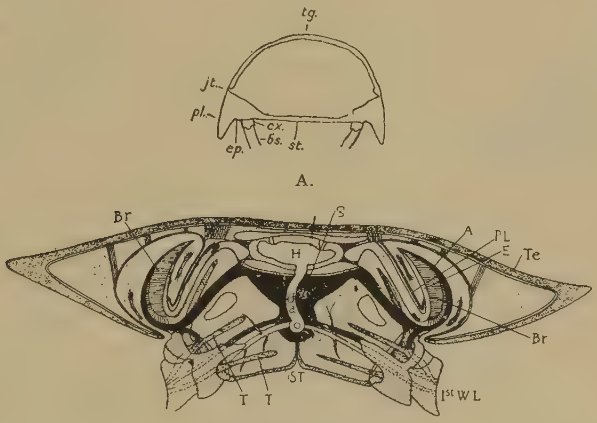
G. Gill (=epipodite.) (After Latter.)

where it meets the body, composed of two portions, a **coxopodite** ( ) and a **basipodite** ( ) which then join the pincer proper. These pincers consist of a solid immovable portion, the **exopodite** ( ) and a smaller movable and inner portion, the **endopodite** ( ).

It will be observed that the pincers are only an enlarged walking leg.

The portion of the crayfish directly behind the cephalothorax, with the definite segmentation, is known as the **abdomen** and consists of six segments, beside the tail. This latter consists of a central portion of the tail called the **telson** ( ), and two pairs of leaf-like structures on each side called **uropods**, which assist in forming a broad wing-like tail and which, when the crayfish is frightened, can be bent rapidly forward, thus sending the animal's body backward from the position it occupied.

A typical segment of the abdomen (Fig. 204) consists of the upper portion called the **tergum** (   ), a ventral portion, the **sternum**, two **pleura** (the extended portions continuing ventrally behind the **sternum**), and two **epimera**, these latter forming the roof which extends from the pleura to the appendage.



A.

B.

Fig. 204.

A. Diagram of skeleton of an abdominal segment of *Astacus*: *bs.* Basipodite. *cx.* Coxopodite of swimmeret. *ep.* Epimeron. *jt.* Point of articulation with skeleton of adjacent segment. *pl.* Pleuron. *st.* Sternum. *tg.* Tergum. (After Latter.)

B. Section through cephalothorax of a crab. (After Pearson.) *H.*, Heart; *Te.*, extension of the tergum; *ST.*, sternum; *PL.*, pleuron; *T.*, tendons; 1*st W. L.*, insertion of first walking leg; *Br.*, gill in gill-chamber; *g.*, gut; *d.a.*, descending artery; *A.*, afferent branchial; *E.*, efferent branchial.

There are thirteen segments in the **cephalothorax.** The eyes are not counted as appendages. A **cervical groove** forms the separating line between head and thorax. The entire **dorsal shield** of the cephalothorax is called the **carapace** (   ), the jointed end extending between the eyes being known as the **rostrum**, while the portion on the sides covering the gills are the **branchiostegites** (   ). The entire crayfish possesses twenty segments, counting telson and uropods as one.

Each pair of the appendages is slightly different in appearance from any other pair, though there is much similarity between them. The three distinguishing types of crayfish appendages are known as (1) **foliaceous** (   ), (second maxilla); (2) **biramous** (   ), (swimmerettes); (3) **uniramous** (   ), (walking legs).

The female has an opening at the base of the third walking leg through which eggs are exuded. She also possesses a single opening in the midline through which sperm may be inserted. Immediately behind the left walking leg, on the first abdominal segment, a peculiar **atrophied** ( ) **pair** of appendages are found.

In the male, however, these appendages on the first and second abdominal segment are wide, and the left walking leg possesses a small opening through which the sperm are ejected. In the male the first pair of swimmerettes are also transformed into "copulating organs." The anal opening is found on the ventral surface in the midline of the telson.

SERIAL HOMOLOGIES AND ADAPTATIONS

When two parts of an organism develop alike as to structure, for example the femur in the thigh and the humerus in the upper arm, we call such bones or parts **homologues** ( ).

And when two parts function similarly, regardless of whether they are alike structurally, we call such organs or parts **analogues** ( ). While if any organ or part of an organ changes, due to a change of environment so as to better or benefit an organism, we call such change an **adaptation**. In the crayfish there is what is called a **serial homology.**

This type of "homology" is characteristic of the group of the **higher crustacea** known as the sub-class **Malacostraca** ( ), and this group well illustrates how a single plan of structure may run through a series of forms of the utmost **diversity in appearance,** and how parts essentially alike may be **adapted** to the most diverse ends.

"The Malacostracan body, be it an **amphipod** ( ), an **isopod** ( ), a **decapod** ( ), or what not—is composed of a series of twenty* segments, each of which is essentially of the skeletal plan shown in the diagram, except that the appendages of the foremost segment are typically unbranched and the hindmost segment (the telson) is rudimentary and bears no appendages at all. Some of these segments may become fused together and consolidated on the dorsal side, only the appendages and ventral margins remaining free. This may occur at either end of the body, but **it occurs constantly in the five front segments,** these by fusion forming the head. The appendages of these five segments **always consist of two pairs of antennae at the front, one pair of mandibles beside the mouth, and two pairs of maxillae following the mandibles."** These parts and their functions will readily be understood a little later because of their likeness to the parts bearing the same names in the insects shortly to be studied. "Immediately following the maxillae are one or more pairs of maxillipeds, likewise directed forward beneath the mouth to assist in the manipulation of the food. Then follow legs and swimmerettes in more or less variety, the terminal joints of some of the legs being modified in many cases into highly specialized grasping organs called pincers, or chelipeds, and the swimmerettes being frequently modified to serve reproductive or

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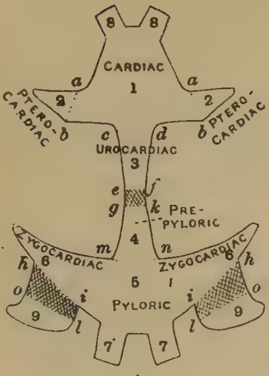
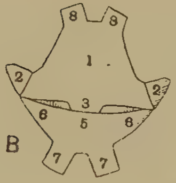
*This is not counting a vestigial segment in the head region, that is discoverable only during embryonic life.



A



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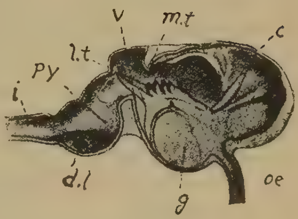
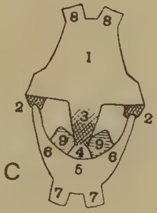
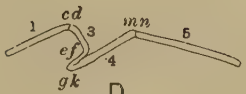


E



C



D

A to D. Diagram of model gastric mill which can easily be made. After W. E. Roth, A, Cardboard as first cut out; B, Model complete at rest; C, Model complete; muscles contracted; D, Median vertical section of model to show folds.

Instructions:

Cut out a piece of card shaped as in Fig. A. Along *ab*, *cd*, *ef*, *hi*, and *mn* cut just the surface of the card with a penknife; do the same, but on the opposite face of the card, along *gk* and *lo*. Then bend slightly downwards the triangular pieces 2, 2; turn 9, 9 under the piece 6, 5, 6 until the lower surfaces of 9, 9 are flat against that of 6, 5, 6: stitch the shaded part of 9, 9 firmly by thread or fine wire to 6, 5, 6; then bend the unshaded part of 9, 9 till at right angles to the shaded part, using *lo* as hingeline. These projecting pieces of 9, 9 then represent the lateral teeth.

Next bend the piece 1, 3, 4 upon hinge-line *gk*, until the shaded portion is flat upon the surface of 4, where it must be securely stitched; this done bend back 1, 3 on hinge-line *cf* until 3 is at right angles to 4. The projecting end of 4 made prominent by these folds represents the central tooth. The piece 1 must now be bent gently downwards upon 3, using *cd* as hinge-line, and 4 must be bent sharply on 5, using *mn* as hinge-line. Lastly, perforate the corner of 6, 6 and of 2, 2, and by a single wire (to allow a certain amount of rotation) unite right hand 2 to right hand 6, and left hand 2 to left hand 6, in each case 2 being outside 6. To do this 6, 5, 6 must be bent like a bow, its right and left arms being thrust downwards and inwards. The model will then be as in Fig. B.

If now the pieces 8, 8 and 7, 7, which represent the anterior and posterior gastric muscles, are pulled so as to represent the effect of a muscular contraction the three teeth come sharply together, but are separated again and the whole model brought back to its original condition by the elasticity of the cardboard. Of course in the actual stomach of the crayfish the gaps between the ossicles are filled in with thin, flexible chitin. By carefully adjusting the size and direction of the 3 teeth in the model and further by hardening them with sealing-wax or similar material, they may be made to grind bread, etc., into small fragments. A sectional view is shown in Fig. D.

E. Stomach or "gastric mill" of the crayfish cut through the middle. *c*, cardiac regions of stomach; *d.l.*, duct from the liver; *g*, gastrolith, or calcareous disk secreted by the walls of the stomach; *i*, intestine; *l.t.*, lateral teeth of grinding apparatus; *m.t.*, median tooth; *oe*, œsophagus; *py*, pyloric region; *v*, valve between cardiac and pyloric regions of stomach. (After Hatschek and Cori.)

respiratory functions. The eight segments following the head constitute the thorax and the seven last segments (counting the rudimentary twentieth segment), the abdomen.

"Crustaceans being primitively free-swimming aquatic animals, it is their swimming appendages that are **least altered by adaptations.** The legs are the stoutest of the appendages, and these offer but one branch arising from the basal piece, and that composed of a reduced number of highly differentiated segments. A comparison of a leg with the last maxilliped in the crayfish will show which appendage has been lost and which preserved and specialized. The best clues to interpretation of homologies in any appendage are likely to be found in other adjacent appendages, which, because of proximity, have been subject to somewhat similar influences."

THE DIGESTIVE SYSTEM

Crayfish live chiefly on living snails, tadpoles, young insects, and the like, but sometimes eat one another, and may also devour decaying organic matter. They feed at night, being most active at dusk and daybreak. The **maxillipeds** and **maxillae** hold the food while it is being crushed into small pieces by the **mandibles.** The food particles pass down the **oesophagus** into the anterior, **cardiac chamber of the stomach,** where they are ground up by a number of **chitinous ossicles** forming the **gastric mill** (Fig. 205). When fine enough, the food passes through a sieve-like strainer of **hair-like setae** into the **pyloric chamber** of the stomach; here it is mixed with a **secretion from the digestive glands** brought in by the **hepatic ducts.** The dissolved food is absorbed by the walls of the intestine. Undigested particles pass on into the posterior end of the intestine, where they are gathered together into faeces, and egested through the anus.

THE CIRCULATORY SYSTEM

As in the frog, the liquid nourishing fluid, the blood, is pumped by the heart (Figs. 206, 207) through the arterial system to the different parts of the body. The blood of crayfish is generally colorless, or pinkish in hue, but on standing, especially if exposed to air, it assumes a bluish color. This is due to **Haemocyanin,** a respiratory protein, which has copper in its nucleus.

Before moulting, the blood of the crayfish is pink in color, due to a dissolved pigment, **Tetronerythrin,** a lipochrome, which is probably deposited in the new chitinous covering, since it is present in less quantity in the blood after the complete formation of the new exoskeleton.

The blood of the crayfish transports food, gases, and wastes, similar to the frog.

The crayfish does not possess a true venous system and the heart has only a single large cavity. The open spaces in the animal's body through which the blood is returned to the heart are called **sinuses.**

The heart itself, lying close to the dorsal surface of the midline, constricts when filled with blood. This constriction sends blood **posteriorly** through the **dorsal abdominal artery,** which lies on the dorsal surface of the intestinal tract, and through a short branch known as the **sternal artery,** which **passes downward** crossing the intestinal tract. The blood is also thus sent to the **ventral thoracic artery anteriorly, and posteriorly** to the ventral part of the body through the abdominal artery.

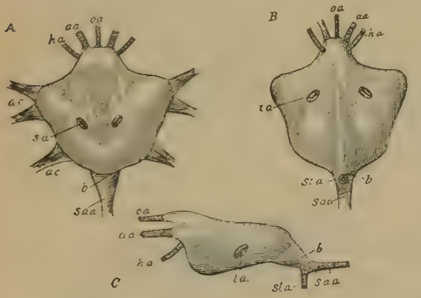


Fig. 206.

Astacus fluviatilis. The heart *A*, From above; *B*, from below; *C*, from the left side: *a.a.*, Antennary artery; *a.c.*, alæ cordis, or fibrous bands connecting the heart with the walls of the pericardial sinus; *b*, bulbous dilatation at the origin of the sternal artery; *h.a.*, hepatic artery; *l.a.*; lateral valvular apertures; *o.a.*, ophthalmic artery; *s.a.a.*, superior abdominal artery; *st.a.*, sternal artery in *B* cut off close to its origin. (From Dougherty after Huxley.)

The arteries passing out of the anterior portion of the heart are the **ophthalmic,** supplying the stomach, oesophagus, and head, and the two **antennary,** carrying blood to the stomach, antennae, excretory organs, and the various other tissues of the head. The **two hepatic arteries** lead to the digestive glands.

When the blood is forced through the arterial system, the heart naturally collapses, and the blood which has been sent out forces the blood which is then present in the arteries to be sent forward through the glands. These glands act similarly to the lungs in the higher forms of animals, aerating the blood and sending it to the large open place around the heart known as the **pericardial sinus.** The heart itself has **two openings on both dorsal and ventral surfaces,** and **one on each side.** The heart muscles, after constriction, again assume their normal state when the blood in the pericardial sinus seeps through the six heart openings, filling the cavity. Each of the openings possesses a valve which prevents the blood from passing out, except through the arterial channels.

It is interesting to note that this method is just the reverse of that occurring in the fishes where the blood passes through the heart first and thence to the gills, while in the crayfish it is the returned blood that passes through the gills before reaching the heart.

Unless colored matter of some kind is injected into the circulatory system the student will probably have some difficulty in finding either heart or arteries.

Valves are present in all the arteries at the point of connection with the heart, and blood passes into numerous capillaries and thence into the open spaces between the tissues, until it reaches the external sinuses, from which it enters the gill channels, to pass into the gill filaments where oxygen from the water in the branchial chambers is exchanged for the carbonic acid that is held in solution in the blood. From here it passes by way of other gill channels into the branchio-cardiac sinuses; thence to the pericardial sinus into the heart.

THE RESPIRATORY SYSTEM

The crayfish, living in, and breathing through water, has **branchial chambers** which contain gills (Fig. 204, B) instead of lungs to form its respiratory system. These gills are **pyramidal** in shape and are thrown out into many flaps or **lamellae** closely packed together. Each gill has a **ventral and a dorsal vessel** through which the blood from the **body cavity** passes into the gills, spreading out through tiny **capillaries** into the **lamellae** ( ), being continuous with similar capillaries emptying into the dorsal vessel.

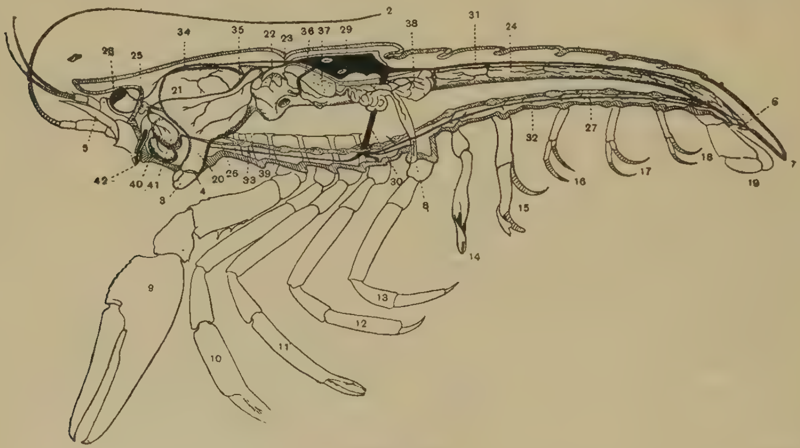


Fig. 207.

Semi-diagrammatic view of internal organs, and some limbs of right side of a male Crayfish. *Astacus fluviatilis*. 1. Antennule. 2. Antenna. 3. Mandible. 4. Mouth. 5. Scale or squama of antenna, exopodite. 6. Anus. 7. Telson. 8. Opening of vas deferens. 9. Chela. 10. 1st walking leg. 11. 2nd walking leg. 12. 3rd walking leg. 13. 4th walking leg. 14. 1st abdominal leg, modified. 15. 2nd abdominal leg, slightly modified. 16. 3rd abdominal leg. 17. 4th abdominal leg. 18. 5th abdominal leg. 19. 6th abdominal leg, forming with telson the swimming paddle. 20. Œsophagus. 21. Stomach. 22. Mesenteron, mid-gut. 23. Cervical groove. 24. Intestine. 25. Cerebral ganglion. 26. Para-œsophageal cords. 27. Ventral nerve-cord. 28. Eye. 29. Heart. 30. Sternal artery. 31. Dorsal abdominal artery. 32. Ventral abdominal artery. 33. Ventral thoracic artery. 34. Ophthalmic artery. 35. Antennary artery. 36. Hepatic artery. 37. Testis. 38. Vas deferens. 39. Internal skeleton. 40. Green gland. 41. Bladder. 42. External opening of green gland. (From Latter after Howes.)

The venous blood in all parts of the body other than the gills, passes through what is called an **open sinus system,** whereas in the gills themselves the **anastomosing arch of the arterial and venous capillaries forms a closed system.**

The thin-walled flaps of the gills are in contact with the water, which is sent through the branchial chamber by the muscles of the **scaphognathite** ( ), a sort of scoop consisting of **the fused bract and exopodite** of the second maxillae. This scoop bales the water out of the forward end of the gill chambers. The **swimmerettes,** being in constant motion, send water forward to the gill chambers. The blood thus comes in contact with fresh water, is **aerated**, and gives off its **carbon dioxide.** Some of the gills are on the appendages themselves, these being the **podobranches** ( ), while those on the basal part of the appendix are called **arthrobranches** ( ), on account of being on the joint itself, while those which originate on the body-wall are the **pleurobranches** ( ).

THE EXCRETORY SYSTEM

Contrasting interestingly with many of the other animals studied in the laboratory, the excretory organs of the crayfish are in the head region. They consist of two rather **large green glands** (Fig. 207), just in front of the oesophagus, with a thin-walled dilated portion called the **bladder**, and a **duct** opening to the exterior through a **pore** at the top of a **little elevation on the basal segment of the antenna.**

THE NERVOUS SYSTEM

The nervous system (Fig. 208, B) is very much like that of the earthworm. The central nervous system is made up of a **ventral chain of nerve ganglia**, though it lies dorsal to the central blood vessel. The ventral chain possesses a **ganglion** for practically every segment, from its posterior end forward. The seventh is called the **sub-oesophageal** ganglion.

The brain sends nerves to the eyes, antennules, and antennae. The sub-oesophageal ganglion, lying in segment seven, is made up of the ganglia from segments three to seven fused together. These send nerves to the mandibles, maxillae, and first and second maxillipeds. **Visceral nerves** are also supplied from the brain, extending posteriorly to the viscera.

THE SPECIAL SENSE ORGANS

Each eye (Fig. 208, A) is made up of some 2,500 little square facets. The long rod extending immediately behind each facet is called an ommatidium. It is supposed that the crayfish can thus see moving objects much better than it could did it have an eye similar to higher forms. But there being so many facets, it is assumed that the animal obtains what is called a **mosaic image**, an image made up of a great many separate and distinct views. However, as Latter says, "We must not confuse this image that we think the animal obtains with the impression that is given it, for the human eye sees an inverted image but the impression is just the opposite."

Although each ommatidium has a small range of vision and forms a **stiple** or **mosaic** image, it has been calculated that the range of adjoining ommatidia overlaps so that a continuous picture or image is formed.

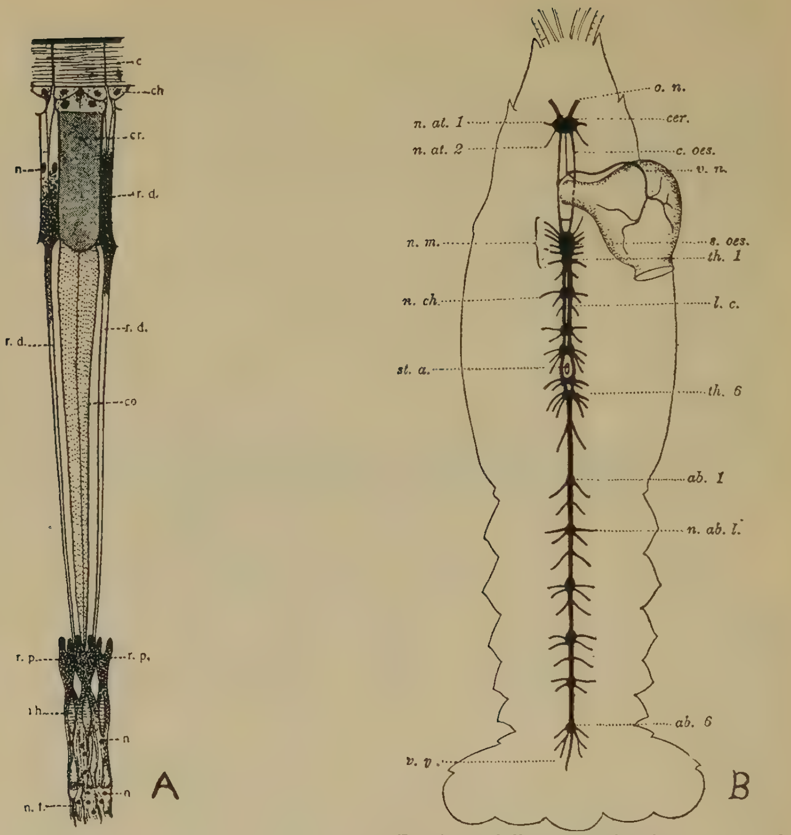


Fig. 208. Ommatidium and Central Nervous System.

A. An ommatidium or eye-element from the eye of the *Lobster* (after G. H. Parker). *c*, cornea (cuticle); *c.h.*, corneal hypodermis, which secretes the cuticle; *co.*, cone cells; *cr.*, crystalline cone; *n*, nuclei; *n.f.*, nerve fibres; *r.d.*, distal or outer retinula cells; *r.p.*, proximal or inner retinula cells; *rh.*, rhabdome.

B. A semi-diagrammatic view of central nervous system of a crayfish. *ab.*1, *ab.*6, *The* first and sixth abdominal ganglia; *cer.*, cerebral ganglion; *c.œs.*, circumœsophageal commissure; *l.c.*, longitudinal commissures of ventral cord; *n.ab.l.*, nerves to abdominal limbs; *n.at.*1, nerve to antennule; *n.at.*2, nerve to antenna; *n.ch.*, nerve to cheliped; *n.m.*, nerves to limbs adjoining the mouth; *o.n.*, optic nerve; *s.œs.*, subœsophageal ganglion; *st.a.*, sternal artery; *th.*1, *th.*6, first and sixth thoracic ganglia; *v.n.*, nerve to proventriculus; *v.n'.*, nerve to hind-gut. (After Borradaile.)

Thus, three adjoining facets might view the word "Biology" in this way:

Bio olo ogy.

That is, facet one, would see the first three letters, facet two the middle three, and facet three the last three. But since the range of each facet overlaps that of the adjoining, the image formed is actually this:

Bio ogy
olo

In other words, instead of an **apposition image** or mosaic, a **superposition image** or continuous picture is formed.*

---

*Microphotographic studies have definitely demonstrated that the account here given is the correct one.

It is doubtful whether the crayfish can hear. Some of the older texts speak of an **otocyst** ( ), but the newer ones have discarded this name entirely, for that organ, which was supposed to be used for hearing, has come to be considered a **balancing organ** by which the animal knows whether or not it is right side up and which, thereby, makes it possible for the crayfish to adjust its position and direction.

These little chitinous lined sacs on the basal segment of each antennule are now called **statocysts** ( ). There are a number of **sensory hairs** in this sac and a few grains of sand called **statoliths.** These latter are placed there by the crayfish itself. These little sand grains coming in contact with the sensory hairs make it possible for the animal to determine its direction and position while swimming. The statocysts are therefore called **organs of equilibrium.** The statocyst **is shed whenever the animal molts.**

We do not know whether the crayfish has a definite sense of smell or not. When meat juices or tiny particles of meat are so placed in the water that a slight current carrying some of the meat comes close to the animal's feelers, it begins working its jaws. This may be either **a sense of touch, or taste or smell.**

MUSCULAR SYSTEM

As the crayfish possesses an exoskeleton all of the muscles are attached to the interior of its casing, the strongest ones being in the abdomen by which that part of the body can be bent quickly and easily, producing a powerful stroke in the water and shooting the body backward rapidly. All of the appendages likewise are supplied with muscles. The muscles are very beautifully arranged, quite complicated and rather **difficult to work out by the student.**

REPRODUCTION

Crayfish are **dioecious,** that is, the two sexes are separate (Fig. 209). The male (cambarus) possesses tri-lobed testis (an anterior pair and a single posterior lobe) in which the spermatozoa arise which pass through the **vasa deferentia** ( ) out of the paired **genital openings,** in the base of the first abdominal appendage.

In the female there is a bi-lobed ovary in which the eggs are found. These, upon ripening, pass through the parent oviducts out of the genital openings, one of which is located in each base of the third walking leg. The sperm are transferred from the male to the **seminal receptacle** of the female during copulation, which takes place most frequently in the autumn. The seminal receptacle itself is a cavity in the fold of the cuticle between the fourth and the fifth pairs of walking legs.

The eggs are usually laid in April and probably fertilized at that time. The female exudes a sticky substance upon the swimmerettes after lying upon her side for several days and cleaning and polishing them very thoroughly. When the eggs are laid they adhere to the swimmerettes which are moved back and forward through the water, thus aerating them. It takes from five to eight weeks for the eggs to hatch, the larvae clinging to the egg shell. In about two days the first **molting** or **ecdysis** takes place; for any animal possessing an exoskeleton finds it impossible to grow without splitting its exterior covering and getting a new one to take its place.

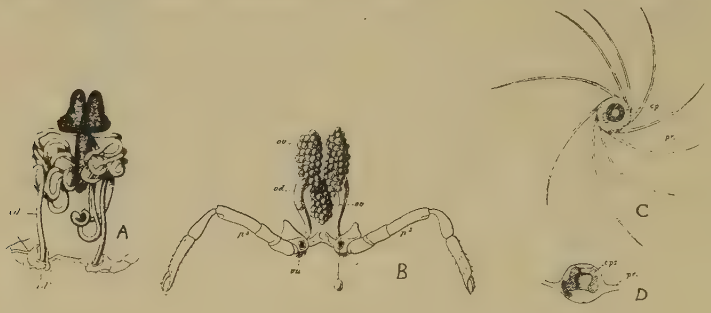


Fig. 209.

A. Male reproductive organs of crayfish.—After Huxley. *t.*, Testes; *vd.*, vas deferens on last walking leg.

B. Female reproductive organs of crayfish.—After Suckow. *ov.*, Ovaries; *ov'.*, fused posterior part; *od.*, oviduct; *vu.*, female aperture on the second walking leg.

C. Spermatozoa of a crayfish. *C.* Whole spermatozoon from above; *D*, part, enlarged, from the side. *cps.*, Capsule; *pr.*, stiff processes. (After Borradaile.)

The young stay with the mother about a month, then shift for themselves. Crayfish attain an age of approximately three or four years. They molt at least seven times during the first summer.

REGENERATION

We have seen how the earthworm, if it is divided in a region posterior to the vital organs, will grow a new tail for the forepart, as well as a new tail-like portion on the tail itself. In the latter case, the animal starves to death, because there is no way of eating.

With the flatworm **planaria**, all manner of fantastic forms may be grown by cutting off, or splitting, or grafting. The crayfish, too, possesses the power of regeneration to some extent, though nowhere nearly as much as the worms. If a leg, eye, or pincer is destroyed (Fig. 210), the animal grows a new appendage, though in place of an eye, it may, and often does, grow an appendage quite similar to one of the walking feet, or even a pincer, depending on how much of the original appendage was destroyed.

AUTOTOMY

An interesting condition of the crayfish, as well as of some of the other crustaceans, is the breaking off, by the animal itself, of one or more of its legs when caught in a position where it seems incapable of extricating itself.

At certain parts of the legs, there is a thick diaphragm with a tiny hole through which blood passes, and it is here that the animal breaks off its own leg, the tiny drop of blood there exposed **coagulating** almost immediately and thus preventing its bleeding to death.

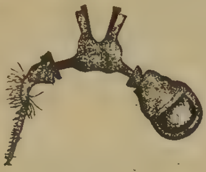


Fig. 210.
Diagram showing antenna-like organ regenerated in place of an eye of *Palæmon.* (From Morgan, after Herbst.)

With an open blood system, such as the crayfish has, bleeding to death would be an easy matter were this special arrangement not made in the animal. A new leg, as large as the one lost, will develop from the stump thus remaining.

Reed says, "Autotomy is not due to a weakness at the breaking point, but to a reflex action, and that it may be brought about by a stimulation of the thoracic ganglion as well as by a stimulation of the nerve of the leg itself."

It will be seen quite readily that this power of autotomy is of considerable advantage to an animal.

PARASITIC CRUSTACEA

Sacculina ( ). (Fig. 212.)

The young are active free-swimming larvae "much like a young **prawn** ( )" or young crab. But the adult bears absolutely no resemblance to such a typical crustacean as a crayfish or crab. The **Sacculina,** after a short period of independent existence, penetrates to the abdomen of a crab, and completes its development while living as a parasite on the crab. In its adult condition it is simply a great tumor-like sac, bearing many delicate root-like suckers which penetrate the body of the crab host and absorb nutriment. The **Sacculina** has no eyes, no mouth parts, no legs, or other appendages, and hardly any of the usual organs except reproductive organs. **Degeneration** here is carried very far.

"Other parasitic crustacea, as the numerous kinds of fish lice which live attached to the gills or other parts of fish, and derive all their nutriment from the body of the fish, show various degrees of degeneration. With some of these fish lice the female, which looks like a puffed-out worm, is attached to the fish or other aquatic animal, while the male, which is perhaps only a tenth of the size of the female, is permanently attached to the female, living parasitically on her."

PLANKTON

One may, with a fine-meshed net, sweep in a considerable collection of organisms from the surface of ponds, lakes, rivers, or ocean. There will be thousands of minute creatures of varying shape and size. Some of them are too small to be seen with the naked eye, while others are easily noticed. Collections of this kind may be made from any waters at any time of the year, from thousands of miles out at sea, and over depths of thousands of feet, to the shore line itself. The reason organisms can be found everywhere in water is due to the fact that their whole life is spent **afloat,** beginning with the egg and reaching through the adult stage. Living organisms of this type have been called **plankton,** and comprise Protozoa, Algae, Diatoms, Rotifiera, and small Crustacea, the latter being especially noticeable.

To permit a life afloat, organisms are provided with various types of **adaptations,** such as minute droplets of oil, long spines to add buoyancy, and gelatinous envelopes. Among the small Crustacea, spines and oil drops are especially abundant. Upon analysis it has been shown that the oil of fish is derived from these small Crustacea. The reason for this is easily understood when it is known that the sole food of several species of whale and of many fish is plankton.

TERRESTRIAL CRUSTACEANS

The Class **Malacostraca** (   ) are Arthropoda, usually of large size, with five segments in the head, eight in the thorax, and six in the abdomen and a gastric mill in the stomach. These, like all other classes, are divided into Orders. Prominent among these orders are the **Decapoda** (   ). The crayfish comes under this grouping. All members of this order have the first three pairs of thoracic limbs specialized as maxillipeds, and possess five pairs of thoracic walking-legs, while all the thoracic segments are generally covered by the carapace. They also have stalked, compound eyes.

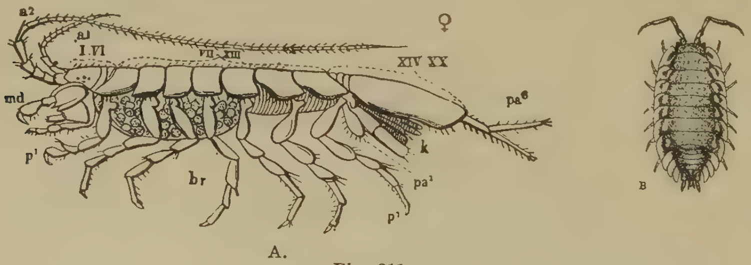


Fig. 211.

A. Ascellus aquaticus *a*¹, *a*² antennae; *br*, brood-pouch; *k*, pleopoda modified to gills; *md*, mandibles; *p*¹-*p*⁷, thoracic feet; *pa*¹-*pa*⁶, abdominal feet (pleopoda); **I-VI,** head; **VII-XIII,** thoracic segments; **XIV-XX,** abdominal segments partly fused. (After Hertwig).

B. Oniscus asellus, a terrestrial species. (After Paulmier).

The **Isopoda** (   ) have a body that is long and flat (Fig. 211, A), seven free thoracic segments, leaf-like legs and no carapace. There are no gills in the thorax.

The five anterior pairs of pleopods are modified for breathing purposes, the endopodites are thin-walled plates, and the exopodites and the whole first pair of pleopods serve as a gill-cover.

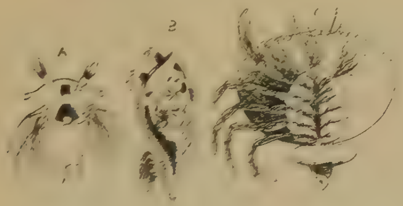


Fig. 212.

Development of the parasitic crustacean, *Sacculina carcinus*: *A*, Nauplius stage; *B*, cypris stage; *C*, adult attached to its host, the crab, *Carcinus maenas*. (After Hertwig).

In the terrestrial **Isopoda** (Fig. 211, B)—the wood-lice—the gills are adapted for breathing damp air. In these, the first and second gill-covers have air-tubes within them. These function like the tracheae of insects and are therefore **physiologically, but not morphologically, comparable** to tracheae.

The many different species of **Isopoda** (except the wood-lice) are aquatic. There are many which are parasitic, feeding on both dead and living fish, and fish in turn feed on them.

A very remarkable finding in the parasite **Cymothoidae** (   ), by Buller, is that the same individual can be developed first as a male and then as a female.

Cryptoniscus (   ) is a more or less shapeless sac which attaches itself to the stalk of **Sacculina** (Fig. 212), and after the host (which is itself a parasite) is killed, the new parasite uses the "roots" of Sacculina to draw forth its own nourishment.

The **Entoniscidae** (   ), parasitic, are usually hermaphroditic, although they have small males, called "complemental males," attached to themselves.

CHAPTER XXII.

INSECTS AT LARGE

It is well first to note that insects (often wrongly called **Hexapoda**, on account of their having three pairs of legs), are winged six-legged arthropods **(Pterygogenea)**, ( ), (Fig. 213). The body is divided into three distinct regions—the **head**, the **thorax**, and the **abdomen.** The head has the following appendages: a single pair of **antennae** ( ); usually **two compound eyes; three simple eyes called ocelli** ( ); and **four different kinds of mouth-parts.** These mouth-parts consist of a **labrum** (single, and not one of the series of metameric appendages), **mandibles, maxillae,** and **labium**; these last three being paired.

The thorax is composed of three segments—**prothorax, mesothorax,** and **metathorax.** Each segment is protected by four exoskeleton plates —a dorsal **tergum,** a ventral **sternum,** and two lateral **pleura.** There is a pair of **walking legs** on each thoracic metamere, while the last two usually also have a **pair of wings** attached.

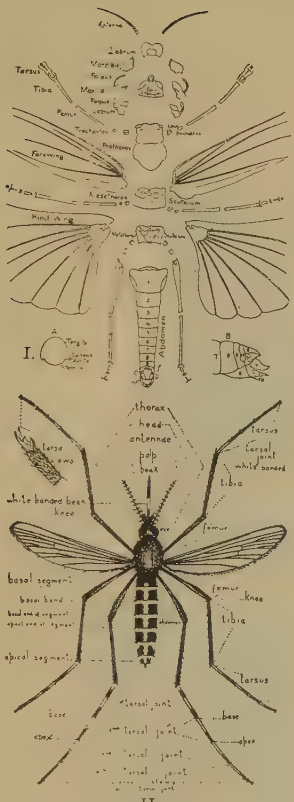
The abdomen usually consists of eleven segments, on which there are no appendages except **accessory reproductive organs** and sometimes a **sting** at the posterior end.

In general there are two types of mouth-parts. These may vary considerably. Grasshoppers and beetles have **biting mouths,** while the **true bugs** have mouths arranged for sucking, and some insects such as the bee have specialized mouth-parts which may be used for either biting or sucking.

The walking legs have five parts: a proximal **coxa** ( ), often fixed immovably to the sternum to which it is attached; a short **trochanter** ( ); a long **femur**; a slender **tibia**; and a **jointed tarsus,** which is usually provided with little hooks or pads, at its free ends. As insects have varying modes of life, such as swimming, flying, digging, and leaping, the legs of each type of insect are **adapted** to the particular functions of each.

It is from the last two thoracic segments that the wings arise. The wings are of two types. Broad ones, such as the butterfly possesses, are used for sailing, while smaller ones like those on flies can be moved quickly, thus causing more rapid movement of the animal. There may be scales or hairs on the wings. Likewise, wings may be thick or thin, light or heavy, and vary in many other ways. The so-called "veins" in insect wings are not veins at all, but thickenings supporting the wings.

As insects are complex organisms, all the interior structures nor-



mally found in any animal, are also found in them, though these may vary considerably as to shape and size. For example, those insects which feed on vegetation have longer digestive tracts than do those feeding on animal matter.

The parts of the digestive system (Fig. 214, E) are: The **mouth** or **buccal cavity**; a slender **oesophagus,** dilated to form a thin-walled **crop**; a muscular **gizzard** or **proventriculus,** a **glandular stomach** or **ventriculus** from which little pouches or **caeca** branch out, and a long slender **intestine.** At the junction of the stomach and intestine the slender **Malpighian tubules** discharge their excretions into the alimentary canal.

Contrary to the higher forms of life no air-breathing insects have lungs. They receive their oxygen through a network of tubes, called **tracheae** which open through little **spiracles** ( ) along the sides of abdomen and thorax (Fig. 215).

If, therefore, one wished to chloroform or drown an insect it could not be done by covering the head or placing the head under water. The abdomen and thorax would have to be covered with the anaesthetic or the water.

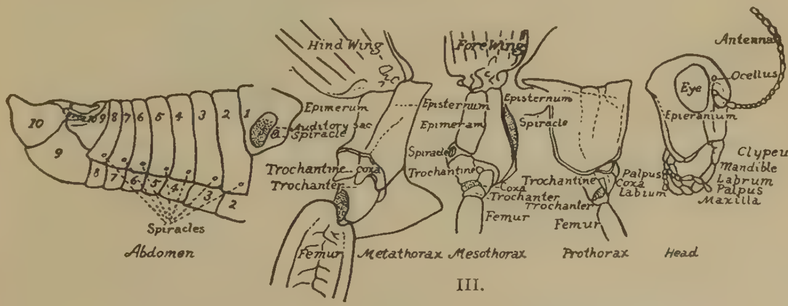


Fig. 213.

I. External anatomy of *Calopte'nus spre'tus,* the head and thorax disjointed; *up,* Uropatagium; *f,* furcula; *c,* cercus. (Drawn by J. S. Kingsley).

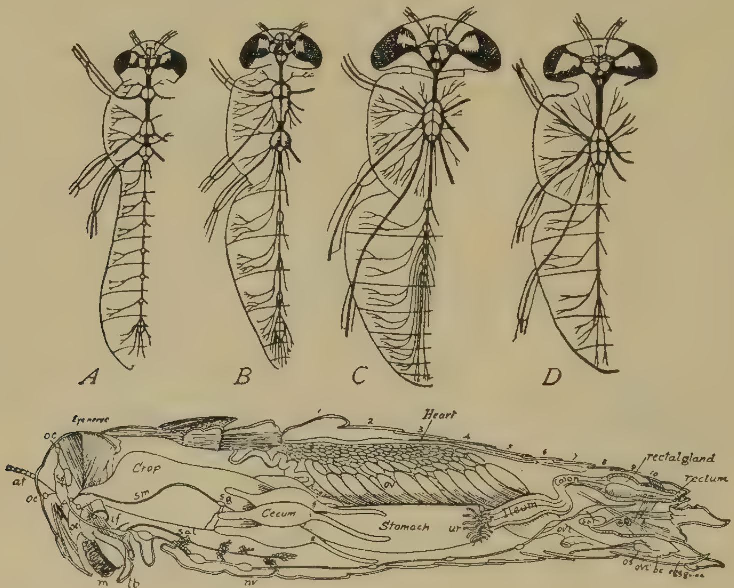
II. An adult mosquito, much enlarged, with all the parts that are used in classification named. (Smith, N. J. Experiment Station, Bulletin 171, 1904).

III. Side view of Locust with the Thorax separate from the head and abdomen divided into three segments. (I, III, from Packard's "Zoology," by permission of Henry Holt & Co.)

If the insect flies a great deal these tracheae are expanded into **air sacs,** which adds to the lightness of its body.

However, those insects living in water have tracheal or blood gills, or both, or at least some specialized adaptation by which oxygen may be used.

A peculiar feature of all animals possessing an exoskeleton is, that as soon as the inside of such skeleton grows but slightly, it becomes too large for its skeletal jacket, so that it must split and a new one form. This is called **ecdysis** (   ), or moult (Fig. 227), and the periods between moults are called **"instars."**



E.

Fig. 214.

A.-D. Successive stages in the concentration of the central nervous system of Diptera. *A, Chironomus; B, Empis; C, Tabanus; D, Sarcophaga.* (After Brandt).
E. Internal anatomy of *Calopte'nus fe'mur-rubrum*: *at,* Antenna and nerve leading to it from the "brain" or supra-esophageal ganglion (*sp*); *oc,* ocelli, anterior and vertical ones, with ocellar nerves leading to them from the "brain;" *oe,* œsophagus; *m,* mouth; *lb,* labium or under lip; *if,* infra-esophageal ganglion, sending three pairs of nerves to the mandibles, maxillae, and labium respectively (not clearly shown in the engraving); *sm,* sympathetic or vagus nerve, starting from a ganglion resting above the œsophagus, and connecting with another ganglion (*sg*) near the hinder end of the crop; *sal,* salivary glands (the termination of the salivary duct not clearly shown by the engraver); *nv,* nervous cord and ganglia; *ov,* ovary; *ur,* urinary tubes (cut off, leaving the stumps); *ovt,* oviduct; *sb,* sebaceous gland; *bc,* bursa copulatrix; *ovt',* site of opening of the oviduct (the left oviduct cut away); 1-10, abdominal segments. All other organs labeled in full. (Drawn from his original dissections by Mr. Edward Burgess). (From Packard's "Zoölogy," Henry Holt & Co., Publishers).

It will be remembered that we spoke of a double-life in the frog, not only as applied to its living in water and on land, but as to its beginning life looking very much different from what it does as an adult. Practically all insects go through a **metamorphosis** (   ) of some sort, and this is much more complicated than the change undergone by the frog.

When insects hatch from eggs (Fig. 241, I, II), and are unlike their parent-forms, they are said to be **heterometabolous** ( ); such insects hatch as **nymphs** ( ), a wingless form gradually growing larger and larger wings after each ecdysis until the adult form is reached; **holometabolous** ( ), if there is a complete metamorphosis, such as being born a **worm-like larva** ( ), which takes food for a short time and then goes

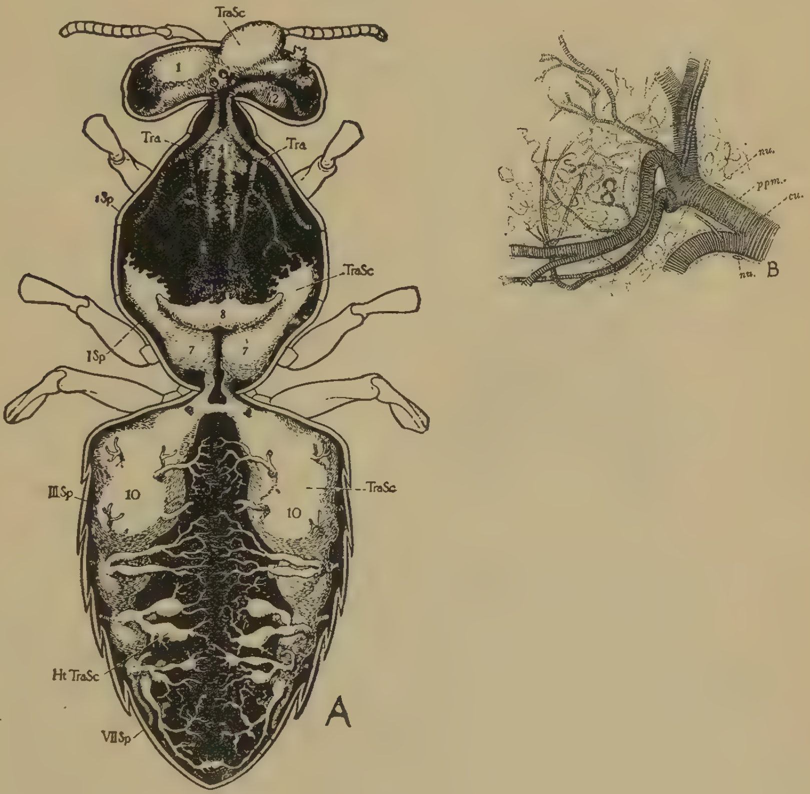


Fig. 215.

A. Respiratory system of worker honey-bee as seen from above, one anterior pair of abdominal sacs removed and transverse ventral commissures of abdomen not shown. *I sp, III sp, VII sp,* spiracles; *HtTraSc, Tra Sc,* 1, 2, 4, 7, 8, 10, tracheal sacs; *Tra,* tracheae. (From Snodgrass, Tech. Series 18, Bur. Ent., U. S. Dep't of Agric.)

B. A portion of the tracheal tissue of a cockroach, highly magnified. Only parts of the tubes are in focus.

cu., Cuticular lining with spiral thickening; *nu.,* nuclei of the protoplasmic layer; *ppm.,* protoplasmic layer continuous with the epidermis ("hypodermis") of the surface of the body. (After Borradaile).

into a **resting** or **pupal** stage during which no food is taken, and during which time it loses all its larval structures, finally developing into a complete adult insect, known then as an **imago** ( ).

In those cases where there is no metamorphosis, the animals are said to be **ametabolous** ( ).

CHAPTER XXIII.

THE GRASSHOPPER

We have seen from our study of the crayfish that it was an arthropod—that is, had hollow jointed feet, and that the Phylum Arthropoda is often divided for convenience into branchiata—(gill-breathing) and tracheata (breathing by air tubes).

The two tracheata most commonly studied in the laboratory are the bee and the grasshopper in this country, and the cockroach in England. Each of these organisms well represents the group to which it belongs. The bee is the more highly specialized and many books have been written about this interesting animal; in fact, so much so that the subject matter covering it is almost inexhaustible. The grasshopper, however, because it is considerably larger than the bee, is preferred by many teachers.

The study of this animal is representative of the greater part of the animal kingdom, for this is an insect, and there are more different kinds of insects than there are of all other animals put together.

Some of our most important garden pests are insects, and it has been estimated by competent authorities, that **one-tenth of all farm products are destroyed by such pests.** Now, there are very few of us who would not object to being obliged to pay one-tenth of all we earned to anyone for the privilege of working; yet, how low our average intelligence **still** is may be noted from the fact, that while a loss of one-tenth of all our food is constant, year in and year out, the average farmer would object very strenuously to paying out even one-tenth of the tenth he loses to pay the salary of a group of trained men to prevent this loss from occurring, although he would thus be increasing his income to a considerable extent.

Let us put this into actual figures. The average farmer, let us say, has an income from all his crops (and this income, of course, includes his living expenses, as he raises the greater portion of his food) at the lowest estimate, $2,000 each year. He should have, if the insect pest were controlled, $2,200. Yet, if he were asked to contribute $20 each year to such control he would rebel. But as each and every one of us must live on what the farmer produces, we must pay $2,200 for $2,000 worth of food. That is, we must pay $100 a year extra for every thousand dollars we spend. Let us consider clothes alone. These may be of cotton, wool, or silk. Cotton and wool are direct farm products, and the silk grower also must have this extra $100 to pay his own expenses in purchasing food for himself and family. In the silk industry **Pebrine**

—a very serious silk-worm disease—causes thousands of yards less of silk to be produced than would otherwise, thereby raising silk prices.

To make this clear to the student, suppose you are employed for a certain number of days each week and a certain number of weeks in the year, and are paid $5 a day for such work; it follows that your employer must receive enough money, when selling the product you produce, to pay you $5 each day, plus a proportionate amount of the rent he pays for the use of the building, taxes, bookkeeping, salesmen's salaries and traveling expenses, as well as allowing interest on the investment. That is, what you get $5 for, will cost the ultimate user at least $10, for, it is just as difficult to sell and to deliver goods as it is to make them. But now suppose a storm comes up and destroys the plant, and you still work, receiving your $5 each day, the traveling salesmen still work, the bookkeeper, stenographer, foreman, engineer, fireman, night watchman, all still are kept on the job, and receive their stated pay, but the work is all put into clearing away the debris and in rebuilding. It follows that all of this expense of keeping these men employed must be added to the cost of the article. This loss may be spread over a great many years, it is true, only a penny or two being added to the selling price of the article, but it must nevertheless be paid.

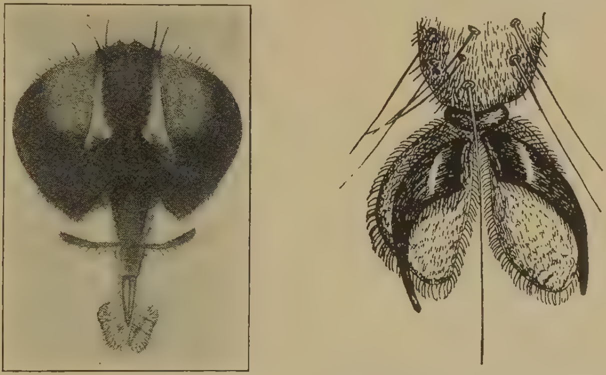


Fig. 216. Head and Foot of Fly.
The Foot shows hooks, hairs, and pads. (Head after Herms).

Now, suppose for a moment, that such a fire takes place regularly every year, and that therefore one must work one-tenth of the entire year without producing anything. This is equivalent to taking your salary away for this tenth of the year though still obliging you to do the work. Here is a parallel to the financial loss caused by insect pests alone, **to you.** For this is **your loss.** You must work an extra five weeks each year to pay for the fact that men at large rank so low in the intellectual scale that they refuse to pay out $10 a year for each $1,000 they receive to prevent tremendous food and clothing losses.

But this mere working of about five weeks each year for nothing is of little importance compared to the **millions of lives lost** each year by the working out of the self-same principle that makes men think only of the dollar they receive to-day, rather than of the ten-times-that-amount they may have to-morrow, if they will but lay the foundations to-day.

Every worker who dies of a disease which could have been prevented, causes each and every one of us to do a portion of his work. This means that we must actually pay the expenses of keeping up such a one's family without anything being contributed on their part.

There is thus an underlying unity among all human beings, in that, whether we will or not, we are our brother's keeper.

This is again well illustrated by taking into consideration the fact that your own home and property may be as clean as it is possible to keep it, but your neighbor's is not. The flies which breed in his manure pile, or in his garbage heap, will come into your home and deposit the neighbor's filth on your food. That this deposit is no mere trifle is shown by an enlarged sketch of the fly's proboscis (Fig. 216).

EXTERNAL APPEARANCE

The hard exoskeleton has already been mentioned as well as the segmentation of the grasshopper's body. The segments in this animal are unlike those of the earthworm in not being all alike.

There is a head, thorax, and abdomen, to which various jointed appendages are attached, a pair to each segment, where any appendages are found at all.

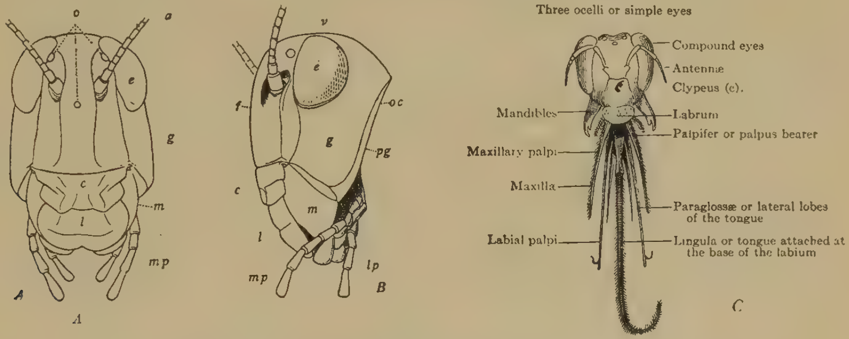
The three pairs of legs formerly gave them the name of Hexapoda. Two pairs of wings are usually found upon the dorsal side of the second and third segments of the thorax, while the tiny outer openings of the tracheae—known as **breathing pores,** spiracles or **stigmata**—are arranged in pairs on each side of two thoracic segments and on all the abdominal segments except the last two or three.

Grasshoppers as well as crickets and cockroaches are members of the order **Orthoptera** ( ). All of this group have mouth-parts (Fig. 217), or jaws formed **for biting and gnawing** as well as two pairs of straight wings, the first pair thickened, the second pair thin, and, when at rest, folded like a fan under the first pair.

A pair of jointed **antennae** or feelers extend forward from the head, while a pair of **large compound** eyes located on the **dorsal epicranium** and **three ocelli** or simple eyes are readily observed. The mouth-parts consist of the labrum or upper lips, being hinged to the **clypeus** ( ), a pair of heavy strong **mandibles** and a **first pair** of **maxillae** with feelers or palps ( ) at the sides, while the **second pair of maxillae** are fused together to form the lower lip, called the **labium,** and are attached to crescent-shaped **genae**

( ). The cheeks are called **genae** ( ), while narrow **postgenae** are back of these.

The maxillae are the **accessory jaws**, being composed of three regions, the **lacinia** or maxillae proper, the **gulea** ( ),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B
Three ocelli or simple eyes
Compound eyes
Antennæ
Clypeus (c).
Mandibles
Labrum
Palpifer or palpus bearer
Maxillary palpi
Maxilla
Paraglossæ or lateral lobes of the tongue
Labial palpi
Lingula or tongue attached at the base of the labium
C

Fig. 217.

A. and *B.* Skull of grasshopper; *C. Melanoplus differentialis.* *a*, Antennae, *c*, clypeus; *e*, compound eye; *f*, front; *g*, gena; *l*, labrum; *lp*, labial palpus; *m*, mandible; *mp*, maxillary palpus; *o*, ocelli; *oc*, occiput; *pg*, post-gena; *v*, vertex (After Folsom).

C. Head and Mouth-parts of an insect. (After Tenney).

the middle spoon-shaped part and the **maxillary palpus**, a special sense organ. This palpus is in turn composed of various segments, the broad basal piece being called the **stipes** ( ) which joins in turn with a smaller **cardo** ( ).

The lower lip or **labium** is composed of two broad terminal flaps called the **ligula** ( ). The **mentum** ( ) is the basal portion, while the small immovable **submentum** lies between the mentum and the gula.

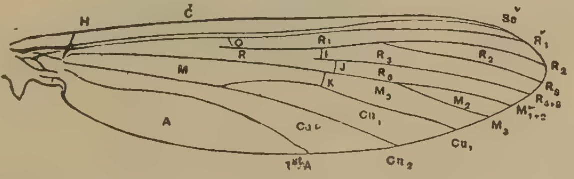

Fig. 218.

The right wing of a male mosquito, *Anopheles maculipennis.* *A*, anal area; *1st A*, anal nervure; *C*, costa; *Cu*, cubitus; *H*, humeral cross-nervure; *I*, cross-nervure between R_2 and R_{4+5}; *J*, cross-nervure between radial and medial systems; *K*, cross-nervure between medial and cubital systems; *M*, media; *O*, cross-nervure between R_1 and R_2; *R*, radius; *Sc*, sub-costa. (From Sedgwick's Zoology, after Nuttall and Shipley).

The thorax is divided into a **prothorax, mesothorax** and **metathorax**, easily distinguished by the three pairs of legs, one pair of which is attached to each of the three thoracic divisions. The prothorax constitutes a collar which is drawn out into a **shield** above. The wings, as already stated, are attached to the dorsal side of the mesothorax and metathorax.

The wings are divided by **veins** or **nervures** (Fig. 218) into so-called cells. Although these veins or nervures vary considerably in different species they are quite constant in members of the same species and so are often used as a basis of classification.

The principal longitudinal veins are the **costa** ( ), **subcosta, radius, media, cubitus** ( ), and **anal.**

There are also cross veins. Any variations are the result of either additional and lessened numbers of those just mentioned. In beetles the fore-wings are sheath-like and called **elytra** ( ). The fore-wings of grasshoppers and all members of orthoptera are leathery and called **tegmina** ( ).

The abdomen consists of eleven segments, the posterior one less clearly defined than the others.

The entire exoskeleton is divided by **sutures** ( ) into distinct pieces, the **sclerites** ( ), though several of these sclerites may fuse.

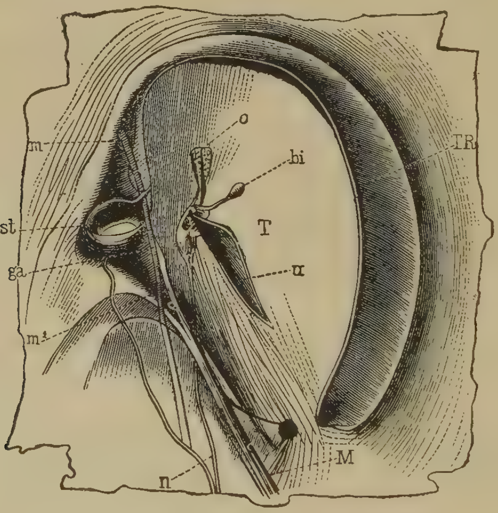

Fig. 219. Ear of Locust (*Caloptenus italicus*) as seen from the inner side.

T, tympanum; *TR*, its border; *o*, *u*, two bone-like processes; *bi*, pear-shaped vesicle; *n*, auditory nerve; *ga*, terminal ganglion; *st*, stigma, or spiracle; *m*, opening muscle, and m^1, closing muscle of same; *M*, tensor muscle of tympanic membrane. (After Graber).

The sclerites (Fig. 204, A) on the dorsal surface are called **tergites** ( ). These are often fused together in various insects. The sclerites on the ventral surface are known as **sternites** ( ), while the side walls connecting dorsal and ventral sclerites are called **pleurites** ( ).

Should one wish to speak of the **entire dorsal portion** it is spoken of as the **tergum** or **notum** ( ), while the **entire ventral** wall is called the **sternum** and the **lateral wall** the **pleuron.**

The last tergum is sometimes called the **suranal** ( )

plate, while the last sternite forms the **subgenital plate.** Below the level of the eleventh tergite, on each side, there is a triangular **podical plate** ( ), and just above each podical plate and projecting backward from the hind margin of the tenth tergite there is a small **copulatory organ,** the **cercus.** In the female this is extremely small.

The **auditory** ( ) **organs** (Fig. 219) lie on the first abdominal segment, which is larger than the others, though not forming a complete ring on account of the hind legs being inserted there. This auditory organ is merely an oval spot of thin skin stretched across a small cavity and connected with a nerve. This is the ear or auditory apparatus.

The posterior portion of a female's abdomen is more tapering than that of the male and is furnished with four blunt spines (six including the inner guide), to form the egg-laying organ, the **ovipositor.** The tip of the abdomen in the male is turned upward.

The first two pairs of legs on the grasshopper are walking legs, while the third pair is used for jumping.

Taking one of the first walking legs, we find five separate divisions (compare Fig. 203 and 213) into which it can easily be separated, namely, the **coxa** ( ), the shortest joint in close proximity to the body; the **trochanter** ( ), the next succeeding small joint almost entirely fused with the coxa in the grasshopper; the **femur** ( ), a long stout section, the **tibia** ( ) following this, also long and quite narrow, and finally the most **distal** portion, the foot, called the **tarsus** ( ) composed of four joints.

There are spines on the leg and claws [also called **ungues** ( )] on the foot, while a **suction disc,** the **pulvillus** ( ), lies between the claws. The longer jumping leg has the same five divisions but the trochanter has fused with the femur, forming a small knob on the inside of the leg.

INTERNAL ANATOMY

THE DIGESTIVE SYSTEM

This consists as in all the other animals studied, of the **alimentary canal** and the **collateral or accessory organs,** the **salivary glands,** and **gastric caeca.**

The alimentary canal itself is a long tube extending throughout the entire body. The **mouth** is the first division and is guarded on each side by laterally moving mandibles. Between these mandibles, and arising from the inner side of the labium, is the short tongue-like organ known as the **hypopharynx,** at the base of which a tube opens from the several salivary glands. The **epipharynx** is the organ of taste, and is located on the slightly convex surface of the inner side of the labrum.

The continuation of the mouth leads into the short curved **oesophagus** which in turn leads to the large **ingluvies** ( ) or crop. Here are seen various rows of spine-like teeth. The **proventriculus** or **gizzard** ( ) follows. This is a very small organ also furnished with spines; it empties into the large, thin-walled **ventriculus** or **stomach.** Six tubular **gastric caeca** or **blind sacs** are attached to the anterior end of the stomach. Posterior to the stomach the alimentary canal forms the intestine, which is divided into three portions: the **ileum** ( ), rather slender, with longitudinal ridges on the inside (the infolding ridges increase the absorbing surface); the **colon,** smaller than the ileum and possessing a smooth lining, and the **rectum,** which has six longitudinal rectal glands of unknown function.

The food of the red-legged locust, which feeds quite freely by day (unlike the crickets and katydids which are more active at night), consists of grass and little drops of dew. The pads at the tips of the legs, and the claws, enable the animal to climb stalks of all kinds very readily. This eating of dew rather than drinking at pools of water, has given us the idea that there is something about standing-water that is fatal to the grasshopper. That this idea is correct is evidenced by the fact that grasshoppers kept in captivity must be **sprinkled** with drops of water or they usually perish.

The food once taken in the mouth finds the salivary glands pouring their secretions forth which thus assist in preparing the food for the crop to which it passes through the **oesophagus.** Here it is mixed with a molasses-colored digestive fluid. It then passes on, being again ground by the spinous processes in the muscular gizzard. The various gastric caeca, each of which has an anterior and a posterior pocket, increase the stomach space.

Once the food has passed through this stage it must become part of the blood of the grasshopper. This it does by being absorbed through the walls of the alimentary tract.

THE CIRCULATORY SYSTEM

The grasshopper has a **long tubular heart** (Fig. 214, E) lying along the dorsal surface just beneath the body wall. From this there are **arteries** and **sinuses** connecting the various parts of the body. From its position the heart is often called the **dorsal vessel.**

Anteriorly the heart is prolonged into a tube leading to the head and is partially divided by **valves** into eight chambers. The position of the heart-valves allows blood to flow **headward only.**

The propulsion of the muscular heart sends the blood forward through various sinuses so that every part of the body may be nourished by it. It then returns by a closed tube, the **ventral sinus,** to the **pericardial sinus** or chamber, and enters the heart through several pairs of

lateral ostia ( ). If more food has been absorbed than can be used, it is stored up as fat in the fat bodies on either side of the heart.

THE RESPIRATORY SYSTEM

The blood of all insects (Fig. 220) contains a respiratory protein, hemocyanin, similar to that of the crayfish. In some few species (bloodworms=midge larvae, Chironomidae) hemoglobin is also found. Since the hemocyanin is capable of absorbing oxygen and carbon dioxide, it is probable that in the insects this respiratory protein aids the tracheae in distributing oxygen and collecting CO_2. The tracheae are kept open and extended by a spiral thickening of chitinous lining and extend to all parts of the body, even including the legs and wings (Fig. 215, B).

This is, no doubt, one of the reasons why the circulatory system is so poorly developed, for, unlike the higher forms of animal life where the circulatory and respiratory systems are dependent upon each other, the systems in the insects are separate and distinct, so that every part of the body can be supplied with oxygen at any time, regardless of what may happen to another part. The disadvantage of such a method consists in the necessity of having both a respiratory system and a circulatory system in every part of the body, instead of having all respiratory work done in one place. The air sacs with which the tracheae are connected are of value in making the animal light for flying and jumping purposes. The grasshopper can beat any professional human jumper by the distance it covers in a single leap when comparative size is considered.

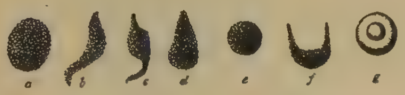

Fig. 220. Blood Corpuscles of the Grasshopper, *Stenobothrus*.
a-f, corpuscles covered with fat-globules, *g*., corpuscle after treatment with glycerine, showing nucleus. (After Graber).

If one notices a grasshopper when it breathes rapidly, it will be seen that the abdomen lengthens and shortens, thus forcing air in and out of the spiracles on the thorax and abdomen.

THE EXCRETORY SYSTEM

Like all animals, the grasshopper needs oxygen to carry on its metabolic processes, and like all animals gives off carbon-dioxide as a waste product, as well as water and a nitrogen-containing-substance called **urea** (if in solution) or **uric acid** (if crystalline). It is interesting to note that those grasshoppers which live in dry places excrete the crystalline product while those which live in damp places excrete the soluble form.*

These excretory products leave the body through the **urinary** or **Malpighian tubules** which empty into the intestine just posterior to the stomach, thus causing both the excreted and egested material to leave the body in the same way. These tubules ramify throughout the body in the animal and are very conspicuous when the body is opened.

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*Doubt has been thrown on former investigations by recent work, so it is well not to assume that our opinions in regard to the work of the Malpighian tubules or of the formation of urea are final.

THE NERVOUS SYSTEM

The nervous system closely resembles that studied in the crayfish, there being a series of **ganglia** along the **ventral nerve cord** which split at the oesophagus, one-half of the cord passing dorsalward on each side of that organ, uniting again on the dorsal surface and forming the **supra-oesophageal ganglion** or **brain,** while the ganglion below the oesophagus which branched to permit the passing around to form the brain, is known as the **suboesophageal ganglion.** It is from the brain that nerves go forward to supply the **special sense organs,** such as the eyes, antennae, and labrum, while the mandibles and maxillae are supplied from the suboesophageal ganglion.

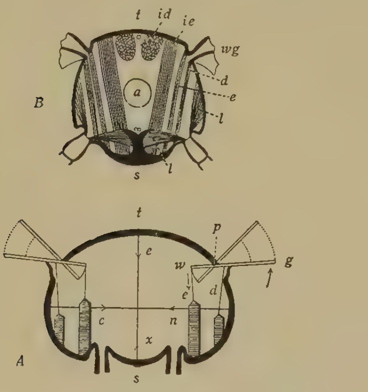


Fig. 221.

A, diagram to illustrate the action of wing-muscles of an insect.

B, diagram of wing-muscles. *a*, alimentary canal; *cn*, muscle for contracting thorax, to depress wings; *d*, depressor of wing; *e*, elevator of wing; *ex.*, expandor of thorax to elevate wing; *id*, indirect depressor; *ie*, indirect elevator; *l*, leg muscle; *p*, pivot or fulcrum; *s*, sternum; *t*, tergum; *wg*, wing. (After Grabers).

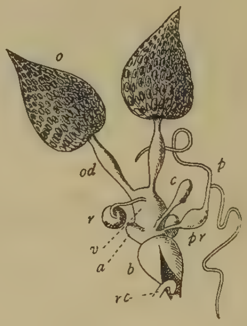


Fig. 222.

Reproductive system of the Queen honey bee. *a*, accessory sac of vagina; *b*, bulb of stinging apparatus; *c*, colleterial, or cement gland; *o*, ovary; *od*, oviduct; *p*, poison glands; *pr*, poison reservoir; *r*, receptaculum seminis; *rc*, rectum; *v*, vagina. (After Leuckart).

Nerves are given off from the thoracic and abdominal ganglia to all parts of the respective segments. The interesting thing about insects is that these nerve centers seem to be as independent as are the separate respiratory tracheae in that the head may be removed while the other parts of the body continue their work almost as well as before. In addition to the **Central Nervous System** and the regular **Peripheral Nervous System,** consisting of these segmental nerve filaments, there is also a **Sympathetic System,** divided into two parts, one lying dorsal to the alimentary tract and controlling processes while the other lies ventral to the alimentary tract and controls the spiracle muscles.

THE SENSES OF INSECTS

We have already seen that there are simple and compound eyes in an insect. An **ocellus,** or simple eye (Fig. 223), is made up of a lens, vitreous body, retina, and nerve, quite like that of the frog, except that the insect's eye is definitely fixed. It cannot accommodate itself to distance. Its power of vision is therefore more limited. The lens being quite convex and only able to focus at one distance, it is assumed that insects must be very nearsighted.

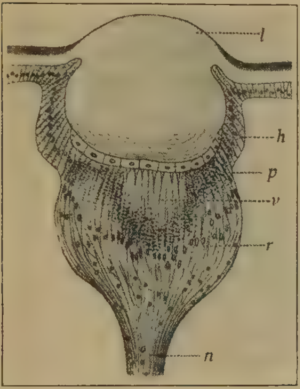


Fig. 223.

Median ocellus of honey bee. (Longitudinal section). h, hypodermis; l, lens; n, nerve; p, iris pigment; r, retinal cells; v, vitreous body. (After Redikorzew).

The surface of the compound eye is made up of numerous facets each at the end of a single eye-element called an **ommatidium** (Fig. 208, A), which, as already described for the crayfish, is, in a way, a separate and distinct eye.

Recent investigations of the structure of ommatidia show that these are more or less conical, the narrow end at the base being connected with the nerve fiber. From this it can be assumed that the field of vision of each ommatidium overlaps slightly that of the adjoining ones. This assumption is further supported by the fact that the lens of each ommatidium is convex, so that not only rays in direct line but lateral rays are refracted on the nerve fiber. In this way a **superposition image** is formed, not the apposition image or mosaic described by older authors.

Recent work on the ocelli and compound eyes indicates both of these structures work together to increase recognition of movement. This is due to the fact that the rays of light reach the ocelli and compound eyes at different angles. There is additional evidence that the ocelli are used to distinguish light from darkness. Certain night-flying bees and dragonflies have greatly enlarged ocelli. Because of the fixed focus of the ocelli and the great convexity of the lens, the object to be seen must be very near.

Whether insects perceive color as such is a question of much dispute. Very little direct evidence is available, most of it circumstantial. Many authors and experimenters hold that insects recognize colors only as shades of gray, much as a color-blind person does. On the other hand, not a single experiment to prove color vision has demonstrated such a fact. It is not a necessary correlation that because flowers are colored, insects see colors. **Half of the good pollinators are night fliers.**

TOUCH

The sense of touch is probably developed very highly in most insects as there are sensory tactile hairs over the entire body, as well as antennae, palpi and cerci which are especially developed tactile organs.

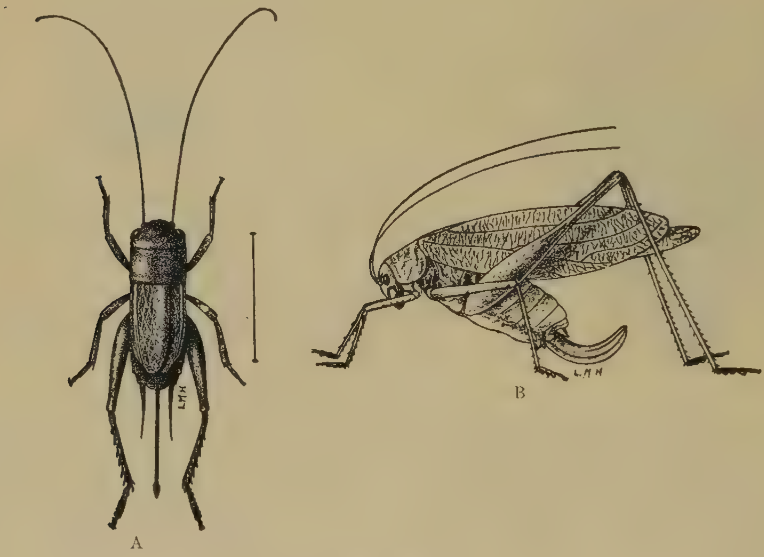


Fig. 224.

A. The common cricket, *Gryllus Pennsylvanicus*, female. Line indicates natural size.

B. Oblong leaf-winged Katydid, *Amblycorypha oblongifolia*, female. (From Kellogg's "American Insects," by permission of Henry Holt & Co.)

TASTE

The sense of taste is located in the sensory hairs or microscopic elevation borne upon the tongue or hypopharynx, on the epipharynx (which lies on the roof of the pharynx), something like the palate in higher animals, and on the maxillary and labial palpi. From the experiments so far performed it seems insects can detect tastes that man cannot.

SMELL

Insects may depend upon the sense of smell to find their food more than upon sight, but the usual experiments to demonstrate this are far from satisfactory. The cutting away of antennae with the attendant tearing of many tiny nerves, will certainly not cause any organism to react normally.

McIndoo has recently shown that the chief olfactory organs (at least in the honey-bee) are located near, or on the base of the leg.

HEARING

As various insects produce noises of many kinds, we infer they **must** hear, though definite evidence has not been forthcoming up to this time. Flies and bees "buzz" by a rapid motion of the wings, while the singing of the male cicada is produced by a rapid vibration of a pair of membranes on the first abdominal segment, and a resounding drum-like membrane within the thorax. Many beetles form a squeaking noise by rubbing their wing-covers against some rasp-like portion of their body, while grasshoppers rub their hind legs against the wing-covers as well as rubbing front and hind wings together.

Crickets and katydids (Fig. 224) have a definite scraper on the base of one wing-cover and a file-like apparatus on the base of the other. These are rubbed together which causes the neighboring membrane to vibrate and produce the "chirp."

As such "chirps" or calls are answered by their mates, it must be assumed that some hearing takes place.

The grasshoppers have a large auditory organ on each side of the first abdominal segment consisting of a surface membrane or **tympanum** stretched across a cavity, on the inside of which two tiny processes something like the ear-bones of the frog are found. There are also similar membranes on the tibia of some insects which may also serve as auditory organs.

A male mosquito will vibrate its antennae when a tone is produced on a tuning fork of the same pitch as that made by the wings of the female, so that it may be that in the mosquito the antennae have some auditory function.

THE MUSCULAR SYSTEM

As in all animals possessing an exoskeleton the muscles must be attached on the inner surface of the skeleton (Fig. 221). Each of these muscles is **innervated** by nerves, however, just as in animals possessing endoskeletons and move by a series of complicated pulley-like arrangements as already seen in the crayfish.

THE REPRODUCTIVE SYSTEM

Among all insects there are two sexes, the male usually being the smaller, more active and more brightly colored. It has been suggested that the reason for this is that the handsomer males are thus able to attract mates more often than those less handsome, and consequently the young born of such more handsome fathers, were also handsome, thus eliminating, by natural selection, the less handsome. It has been suggested by some also that the female, who carries the eggs, by being less gaudy in appearance is also less conspicuous, and therefore not so likely to be caught by natural enemies.

In all female insects there are a pair of ovaries (Fig. 222) usually formed of many small tubes called **ovarioles.** From the ovaries the **oviducts** pass out into a **terminal region,** the **vagina,** which is sometimes also paired. This latter organ is usually formed by an invagination from the outer part of the body until it meets the oviducts, while near this, or branching off from it, there is a **receptaculum** for receiving and holding the male sperm received during copulation.

Then there are **accessory glands** which secrete a sticky substance or cement as the eggs pass through the oviduct. These glands are known as **colleterial** or **sebific** ( ) glands which open in turn into the dorsal portion of a capacious pouch, the **bursa copulatrix,** through a duct. This bursa rests on, and opens directly into, the oviduct of the female. Grasshoppers have an external hard posterior region of the body known as an **ovipositor** (Fig. 225).

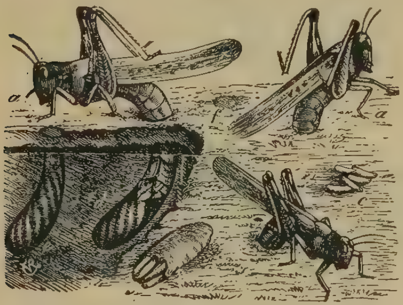


Fig. 225.

Rocky Mountain locust: *a, a, a,* Female in different positions, ovipositing; *b,* egg-pod extracted from ground, with the end broken open; *c,* a few eggs lying loose on the ground; *d, e,* show the earth partially removed to illustrate an egg-mass already in place and one being placed; *f,* shows where such a mass has been covered up. (After Riley).

The males possess a pair of **testes** usually formed of many small tubes connecting with two ducts, the **vasa deferentia** which carry the sperm to the terminal portion called an **ejaculatory duct,** which may have one or two openings. This external opening may be formed by the union of both vasa deferentia or by an invagination meeting these ducts.

The **seminal vesicles,** usually paired, open from either the vasa deferentia or the ejaculatory duct. Here sperm are stored. Often there are accessory glands whose secretion unites the sperm into packets known as **spermatophores.** There may or may not be an external copulatory organ though in the grasshopper there are a pair of these, called **cerci.** Often there are also external hard parts as in the female though, of course, these are not ovipositors.

The sperm are placed in the seminal receptaculum of the female by the male and may remain there for many years. The queen bee only copulates once, and that on her first and only flight, and yet the sperm have remained alive so that eggs which were laid thirteen years afterward were fertile.

There are a few insects which give birth to living young, such as the "parthenogenetic summer aphids, a few flies, the little bee parasites Strepsiptera, a few beetles and cockroaches," but by far the greater portion lay eggs, the young then developing from these.

When eggs develop which have not been fertilized, birth is said to be by **parthenogenesis** ( ). This occurs normally, at least for a number of generations, in two Lepidoptera and one beetle, in some coccus insects and aphids, and in certain saw-flies and gall-wasps. It occurs casually in the silk-moth, in some grouse, locusts, and several other Lepidoptera, seasonally in aphids, in larval life in some flies [Miastor ( ), Chironomus ( )] and partially or "voluntarily" when the queen-bee lays eggs which become drones.

PAEDOGENESIS

Among certain tiny flies hardly one millimeter in length and known as midges (Fig. 226) there are pupae which produce eggs without fertilization. The larvae of the gall-gnat, the related members of this family, and related Chironomidae likewise do this so that here we have a case of a granddaughter commencing to grow and develop not only without fertilization, but before the mother and grandmother themselves become full-fledged imagoes or adult insects.

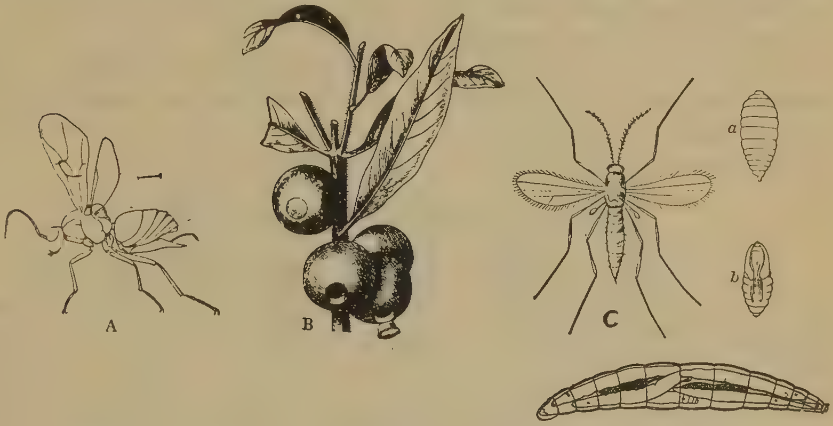


Fig. 226. Order *Hymenoptera.* D.

A, gall-fly, *Rhodiles rosoe*, female. *B*, galls produced by a bug. (A, from the Cambridge Natural History; B, from Davenport, after Kerner).

C. Order *Diptera.* Hessian fly, *Cecidomyia destructor* (one of the midges). *a*, larva. *b*, pupa. (From Davenport, after Standard Natural History).

D. Young paedogenetic larvae of *Miastorca* genus of the family *Cecidomyiidae* in the body of the mother larva. (After Pagenstecher).

The larvae in such cases are hatched within the parent larva and "in some cases escape by the rupture of the body."

Such development of one, two, or three generations within the immature animal is called paedogenesis ( ).

POLYEMBRYONY

In 1904 P. Marchal described an interesting observation. He found that in two small parasitic Hymenoptera ( ), a Chalcid ( )—Encyrtus ( )—which lay eggs in the developing eggs of the small moth Hyponomeuta ( ) and a Proctotrypid ( )—Polygnotus—which infests a gall-midge—Cecidomyid ( )

—larva, the nucleus of the egg of the insects divided and each such particle of nucleus became a complete new embryo. "Thus a mass or chain of embryos is produced, lying in a common cyst, and developing as their larval host develops. In this way over a hundred embryos may result from a single egg. Marchal points out the analogy of this phenomenon to the artificial polyembryomy that has been induced in **Echinoderm** ( ) and other eggs by separating the **blastomeres,** and suggests that the abundant food-supply afforded by the **host-larva** is favorable for this multiplication of embryos, which may be, in the first instance, incited by the abnormal osmotic pressure on the egg."

When many embryos develop from a single egg in the way just described it is called **polyembryony.**

H. H. Newman has shown that in the ant-eater, **armadillo,** in which three to nine embryos commonly form different species, all develop from a single egg. The fertilized egg does not split into separate parts but evaginates in different portions to form separate embryos.

ALTERNATION OF GENERATIONS

A true alternation of generation has been found in Hymenopterous gall flies (Fig. 226), in which a complete asexual generation (complete from egg to adult) succeeds a complete sexual generation (egg to adult), each generation being parasitic on a different host plant. The adults in each case bear no resemblance to each other; in fact, they have not only been described as different species, but actually as different genera.

EMBRYOLOGY

The flapping of wings or the "singing" of the male grasshopper attracts the "unfertilized" females. The sperm are then injected into the female receptacle, from whence they work their way into the various eggs.

The **zygote** thus formed, begins to **segment mitotically,** forming the **embryo** on **top of the yolk** close to the egg-shell. There are two protective membranes, the innermost being known as an **amnion** ( ) or **chorion** ( ), and the outer as the **serosa** ( ). As soon as the embryo has used up the yolk as food it is ready to hatch.

However, all of this process does not take place in the body of the grasshopper. Soon after fertilization the female drills a hole in the ground with the hard portions of the ovipositor and deposits the eggs which are then covered. These hatch in the spring. It is here, in its warm underground cage, that most of the development described above takes place.

"By opening and shutting the ovipositor a hole (Fig. 225), slightly curved, is quickly drilled in the ground. This drilling process goes on until nearly the entire abdomen is buried. Ovipositing females may frequently be found in October. A frothy matter is first laid down from the cement glands, then the eggs and cement are alternatively deposited until some twenty to thirty-five eggs have been laid. Each individual egg is elongated and slightly curved. The female ordinarily oviposits more than once, averaging from 100 to 150 eggs in all. The eggs are placed side by side in four rows, but standing obliquely to the wall in such a way that all slant upward. Since they are all pushed tightly against the wall of the cylindrical burrow the outside rows must project beyond the two inner rows. In this way a channel filled with frothy matter is left along the tops of the rows. Such a grooved arrangement insures the escape of the young from the lower eggs in case those in the upper ones die or are delayed in hatching.

"Each egg is covered by two membranes: (1) an outer thin, semi-opaque one which under a lens may be seen to be pitted or thrown into ridges, and (2) an inner membrane **(chorion)** which is smooth and thick, but so translucent that the young insect can be seen through it after development has begun. While the outer covering is easily broken, the inner is very resistant, requiring strong pressure between the fingers to crush it.

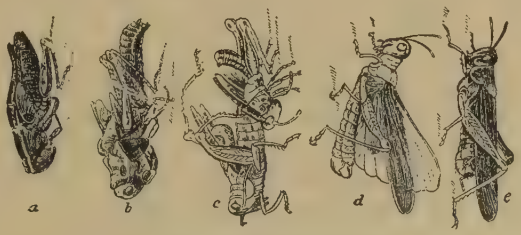


Fig. 227. *Calopt'enus Spre'tus.*

Process of acquiring wings: *a*, Pupa with skin just split on the back; *b*, the imago extending; *c*, the imago nearly out; *d*, the imago with wings expanded; *e*, the imago with all parts perfect, natural size. (After Riley).

"At hatching time in the spring the struggles of the young locust, together with the swelling of parts within the chorion, burst the latter, generally along the ventral side, and the young locust struggles out of its burrow. Once out, it rests a few minutes, generally lying on one side. The limbs are at first limp and directed backward. The animal is still enveloped in a thin veil or pellicle which has aided it in forcing its way out of the ground. This covering shortly splits along the middle of the back and works off behind. Within an hour the locust takes its natural gray color. The foregoing account applies particularly to the Rocky Mountain locust."

The young grasshopper (like all **exoskeletonous animals**), though able to feed immediately when its normal form has been completed, cannot grow until it throws off its outer covering. This ecdysis occurs periodically. Of course, it takes time for the new skeleton to harden, so that immediately after shedding its covering the animal is rather soft. The wings appear after the first moult (Fig. 227). They increase in size with each moult but become **functional** only after the **final moult.** An insect which at birth resembles its parent, but is not entirely like it, as the young grasshopper, is called a **nymph** ( ).

The last moult takes place in the late summer. The nymph then "climbs up some grass stem or similar object, and, taking firm hold, often with its head pointing downward, remains motionless for several hours, till the skin swells over the head and thorax and finally splits open along a median dorsal line. From this old skin the new head, thorax, legs, wings and abdomen are slowly withdrawn while soft, expanding and hardening within half to three-quarters of an hour."

It is then a full-fledged adult and is called **imago.** After the eggs have been laid in the fall most of the locusts die.

BEHAVIOR

As there are more different species of insects than there are of all other animals together, it is not strange that insects should be of considerable interest and importance.

They illustrate better than any other type of animal the interrelationships and interdependence of all living things.

Pollen is carried from one plant to another by insects (Fig. 239), thus permitting vegetation to grow wherever there is sufficient heat and moisture. This makes food more plentiful. Injurious animals and pests are kept down even among their own kind. For example, the swift little **tachina fly** (Fig. 240) pokes its egg between the segments of the grasshopper's abdomen, which egg then develops into a maggot, and this maggot bores its way into the interior of its host, feeding on the living substance as it goes. It leaves the vital organs until last, so that the grasshopper does not die until the maggot has abundantly supplied itself with nourishment. Then, too, insects furnish the most abundant food for birds, worms, toads, fish, and other animals. Even man has not hesitated to use them as food. The Bible speaks of John in the desert feeding on locusts and wild honey; one itself, the insect, the other, the product of an insect.

In the markets of Manila large piles of grasshoppers with their appendages removed are offered for sale, ready for cooking. The Moors fry locusts in butter and they are said to make a very palatable dish. In fact, many of the Indian tribes have been known to use not only grasshoppers, but ants as well, as a part of their diet, while the natives of Uganda keep crickets in a warm oven for their musical sounds. In China it is said that fights are staged between crickets and that this is a favorite method of gambling.

The larvae or **grub** of the **warble fly** is eaten by the Dog Rib Indians, who are fond of caribou which in turn is thoroughly infected with these grubs. The grubs are eaten raw and the children consider them a great delicacy.

To this list may be added moths and caterpillars, eaten by both Pai Ute Indians and the Australian Bushmen, while bugs, beetles and the eggs of these insects complete the list. The Manna of the Old Testament is considered by entomologists to be the secretion, somewhat like honey, from an insect. These manna insects, now called **Gossyparia mannifers** ( ), "infested the smaller branches of **Tamarix gallica** ( ) in large numbers, sucked up sap in quantities, and exuded manna in the form of a sugary secretion which, in the cool of the evening, fell to the ground in solid form, but, after sunrise, melted and percolated the soil."

Conditions of the past have been changed since man has learned to till the soil; for, insects now receive other food, their conditions of life have changed and comparisons of ancient times when men lived under different conditions from the present are often likely to lead one astray. This is particularly noticeable among agricultural peoples who seldom use insects as food. In famines, anything could be relished and it was no wonder that such peoples often turned to a diet not commonly used, and then after an acquired taste had been brought about (just as it is known that practically no one likes olives the first time he eats them, but can acquire a very considerable taste for them later) the children who had been fed upon such diet actually relished it. No better proof of this could be found than the fact that pigeons and rabbits never normally eat meat, but, if they are fed meat alone from birth, they will die rather than eat a normal pigeon's or rabbit's food when they have become fully grown.

In addition to being used as food, insects have formed a great source from which various oils and other medicinal substances have been abstracted from time immemorial. All historical literature is filled with references to this use of insects.

Because all of us need a physician at some time or other, it is of great interest and value to know as much about this subject as possible.

Over against this beneficial use of insects may be placed the great devastations in our own country by the **periodical locusts** which sweep every grain field bare before them, and other crop-injuring pests such as boll weevils, which injure thousands of dollars worth of cotton annually, while almost every grain has some sort of insect which uses such grain as its food.

As carriers of developing eggs or various immature forms of parasites, insects are now known to do great injury to man as well as the animal world at large. The classic example is that of the **anopheles mosquito,** carrying malaria, as also the **tse-tse fly,** already referred to as the carrier of the germ of sleeping sickness.

Lice (Fig. 228), and other so-called **vermin** (all of these belong to the insect group), are not only injurious to higher forms of life by their acts, but also as carriers of disease.

The common house fly carries dirt and filth from the garbage can and manure pile to the food it lights upon, as well as to the baby's drinking bottle. In this filth, it thus deposits, there are hundreds of tiny eggs and seeds which as soon as they receive the necessary moisture and heat

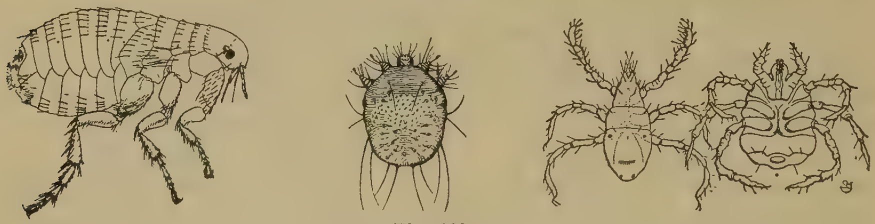
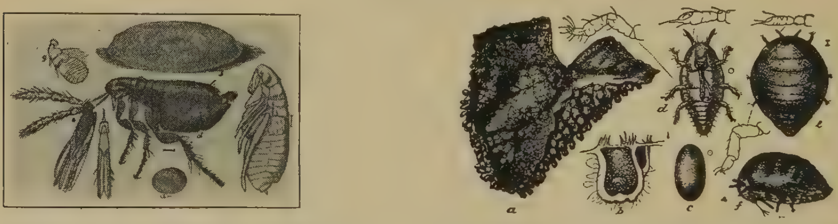


Fig. 228.
Lice—both animal and plant.

A. Female of flea, *Putex irritans*, infesting man. (After Herms.)

B. *Sarcoptes scabei*, female itch mite. (After Leuckart).

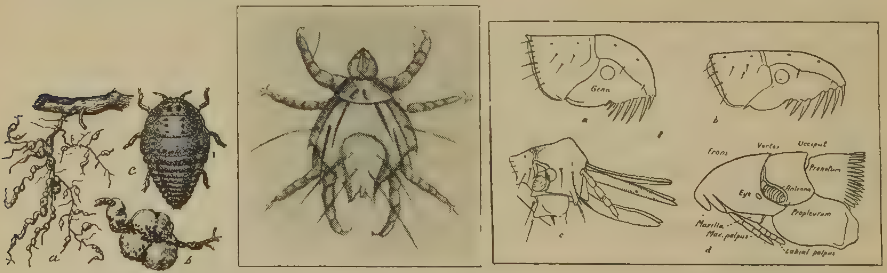
C. Order *Acarina*. Harvestmites or "chiggers." *Leptus irritans* on the right; *L. americana* on the left. (From Osborn, after Riley).



D. Common cat and dog flea (*Pu'lex serrat'iceps*): *a*, Eggs: *b*, larva in cocoon; *c*, pupa; *d*, adult; *e*, mouth parts of same from side; *f*, labium of same from below; *g*, antenna of same; all much enlarged. (Howard, Bull. U. S. Dept. of Agriculture, 1896).

Rat Fleas.—It is believed that in tropical countries the disease germs of the bubonic plague may be transmitted from rats to men by the bites or punctures of rat fleas.

E. *Phylloxe'ra vasta'trix*: *a*, Leaf with galls; *b*, section of gall showing mother louse at center with young clustered about; *c*, egg; *d*, larva; *e*, adult female; *f*, same from side. (*a*, Natural size; *b-f*, much enlarged). (Marlatt).



F. *Phylloxe'ra vasta'trix*: *a*, Root-galls; *b*, enlargement of same, showing disposition of lice; *c*, a root-gall louse, much enlarged. (Marlott.)

G. *Pediculoides ventricosus*, male. Grain louse which affects farmers and threshers. (After Braun).

H. Head and Pronotum of (*a*) dog flea; (*b*) of cat flea; (*c*) hen flea. (After Rotschild.) (*d*) Nycteridiphilus (Ishnopsyhus) hexactenus. (After Oudemans.)

of the interior of the human or animal body, begin to develop. This is the common way in which typhoid fever is carried, for one can hardly get this disease unless some excreted matter from a typhoid patient has been eaten in this way.

An excellent way to demonstrate the fact of insects' eggs being almost everywhere on our foodstuff is to take any fruit, such as a banana, apple, cherry, or grape, and place this in a bottle plugged with cotton, so that air may pass in but nothing else can. In a short time various forms of animal life will be found therein. As these forms of life hatched from eggs, the eggs must have been on the fruit before it was placed in the bottle. It is of value to note that even after one has washed the fruit well, such hatching will almost always occur, showing how thoroughly these insects fasten their eggs either on or into the surface structures of these fruits.

When different kinds of crops are planted different kinds of insects will thrive, as those alone will survive which have a sufficient food supply. Those not feeding on the new plants either leave for satisfactory fields, or die. If it is remembered that a duck, which feeds on fish, tastes totally different from one not so fed, which shows that the food of an animal makes a great chemical difference to the body tissues, it can be understood how different diseases may come forth when parasites change their food and environment. For, if it makes a chemical difference in the flesh of an animal as to what it eats, it means also that if a new chemical substance in a parasite is poisonous to man, then the same parasite when feeding on one food may not be poisonous and not cause disease, whereas when feeding on another type of food, such chemical poison may cause disease. Then there is the interesting fact that many diseases of birds will not affect a frog normally when such disease germs are injected, but, if the frog be placed in an incubator where its blood becomes of the same temperature as that of the bird from which the disease is taken, the disease will develop. This illustrates how different temperatures change the susceptibility of different organisms to different diseases.

The animals commonly called grasshoppers are really of varying types (Fig. 229), the **true grasshopper being long-horned**; that is, it has two antennae as long or longer than its entire body. The family to which these belong is known as **Locustidae**, while the short-horned grasshoppers belong to the family **Acridiidae**.

In America the Rocky Mountain Locust is the one which does the great damage to crops. The exact time of laying and hatching of eggs varies somewhat with the region of the country.

Often the young, until after the second or third moult, content themselves with feeding on whatever food is close at hand, but as soon as this food becomes scarce the animals congregate and "in solid bodies, sometimes as much as a mile wide, march across the country, devouring every green crop and weed as they go. During cold or damp weather and at night they collect under rubbish, in stools of grass, etc., and at such times almost seem to have disappeared; but a few hours of sunshine brings them forth as voracious as ever. When, on account of the immense numbers assembled together, it becomes impossible for all to obtain green food, the unfortunate ones first clean out the underbrush and then feed upon the dead leaves and bark of timber lands, and have often been known to gnaw fences and frame buildings. Stories of their incredible appetites are legion; a friend informs me that he still possesses a rawhide whip which they quite noticeably gnawed in a single night.

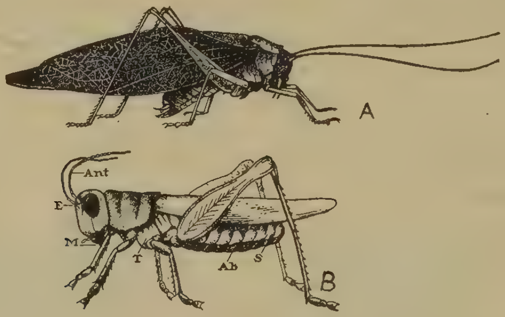


Fig. 229. Long and Short Horned Grasshoppers.

A. Order Orthoptera. Katydid, *Microcentrum retinerve.* (From Sedgwick's Zoology, after Riley.)
B. Red-legged grasshopper (*Melanoplus femur-rubrum*): *Ab,* abdomen; *Ant,* antennæ; *E,* eye; *M,* mouth; *T,* thorax; *S,* spiracles.

"By mathematical computation it has been shown that such a swarm could not reach a point over thirty miles from its birthplace, and as a matter of fact they have never been known to proceed over ten miles."

There are other species and genera which do not migrate from their native haunts at all. Many ingenious ways have been used to exterminate them. Certain fungus growths on plants which the grasshopper uses for food are fatal to him. So, too, is the little tachina fly already mentioned. Such fungus growth and flies are sometimes developed to assist in controlling injurious insects.

The effect of a difference of temperature on insects is well illustrated by the fact that there is only one annual generation of grasshoppers in New England, while there are two in Missouri.

Ditches are often dug in which the animals fall, or kerosene emulsion is poured on water standing about, or placed in simple trough-like wooden movable ditches. Even if the grasshopper crawls out of the oil it dies shortly after.

For the control of grasshoppers, see any of the books mentioned on Economic Entomology, at the end of Chapter XXIV.

CHAPTER XXIV.

THE HONEY BEE

The Honey Bee (Fig. 230) has been studied and written about for centuries as one of the most interesting of insects. It lives a decidedly complex social life and has lent many examples to prophets and teachers of all times.

The bee is intensely specialized in almost all parts of its body, and as such is of great value to any comparative study of the arthropods.

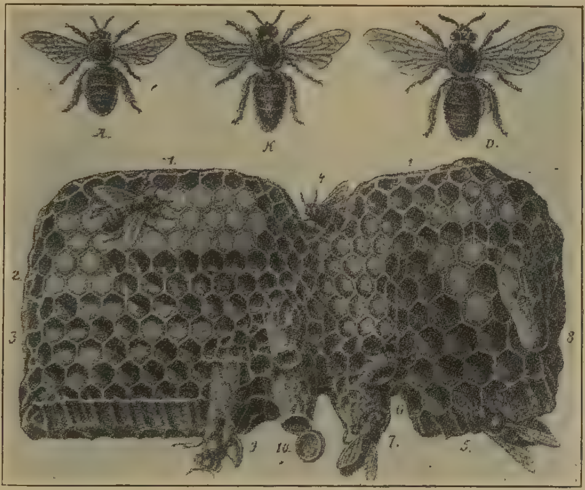


Fig. 230.

Hive bees and comb (after Schmeil). *A*, Worker; *K*, queen; *D*, drone; 1, worker with cells filled with honey and covered; 2, cells containing eggs, larvæ, and pupæ; 3, cells containing pollen; 4, below 4 are regular cells; 5 drone cells; 6-10, queen cells.

Foremost in rank in the hive is the Queen. She is the mother of every member of the hive, for she alone, of all the inhabitants, lays eggs.

With her, in the summer time, there are some sixty thousand workers and several hundred drones. The latter are killed during the winter.

The abdomen of the queen is longer than that of a worker and there is no pollen basket on the tibia of her hind legs.

The **drone** is the male. He lives upon the food gathered by the females. His body is heavy and broad and no pollen baskets are found on the hind legs. His eyes are larger than those of either queen or worker.

The worker is an undeveloped female, which can, however, by proper food, nourishment and care, become a queen in case the old queen dies. The workers are smaller than either queen or drones. They are the ones usually seen hovering about flowers.

Bees have mouth parts (Fig. 231), modified both for biting and sucking, and two pairs of membranous wings.

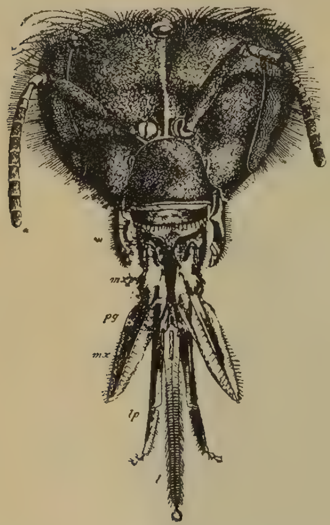
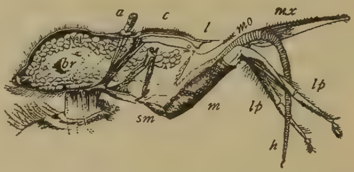
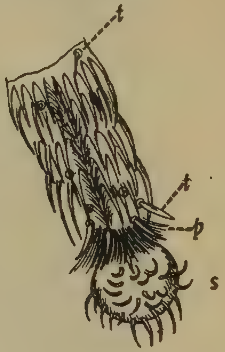


Fig. 231.

A. Front view of the head and mouth parts of a bee.—After Cheshire. *a*, Antenna; *m*, mandible; *g*, labrum and epipharynx; *mx.p.*, rudiment of maxillary palp; *mx.*, lamina of maxilla; *lp.*, labial palp; *l.*, ligula; *b.*, bouton at end. The paraglossæ lie concealed between the basal portions of the labial palps and the ligula.



B. Side view of mouth parts of the honey bee, *Apis Mellifera*. *a*, base of antenna; *br*, brain; *c*, clypeus; *h*, hypopharynx; *l*, labrum; *lp*, labial palpus; *m*, mentum; *mo*, mouth; *mx*, maxilla; *sm*, submentum. (After Cheshire.)



C. Tongue of honey bee. *p.*, protecting bristles; *s.*, terminal spoon; *t.*, taste setae. (After Will.)

EXTERNAL APPEARANCE

The body is divided into head, thorax, and abdomen. (Fig. 213.) The body is covered with a skin or cuticle which is composed of a thin chitinous layer produced by the secretion from the cells lying beneath it. This serves as a protection, but it is cast off at various intervals during the early stages of growth.

There are a pair of **large compound eyes** and three **ocelli or simple eyes.** The arrangement of the ocelli are somewhat different in queen, worker, and drone. Two feelers **(antennae)** project from the front of the head.

The mouth is made up of an upper lip or **labrum,** an **epipharynx,** a **pair of mandibles, two maxillae,** and a **labium.** This latter is the under lip.

The labrum is joined to the **clypeus** (the dome-shaped portion of the skull), (Figs. 217 and 231), lying just above it. The **epipharynx** is the fleshy projection extending beneath the labrum. It serves as an organ of taste. The jaws or mandibles lie on each side of the labrum, being notched in the queen and drone, and smooth in the worker.

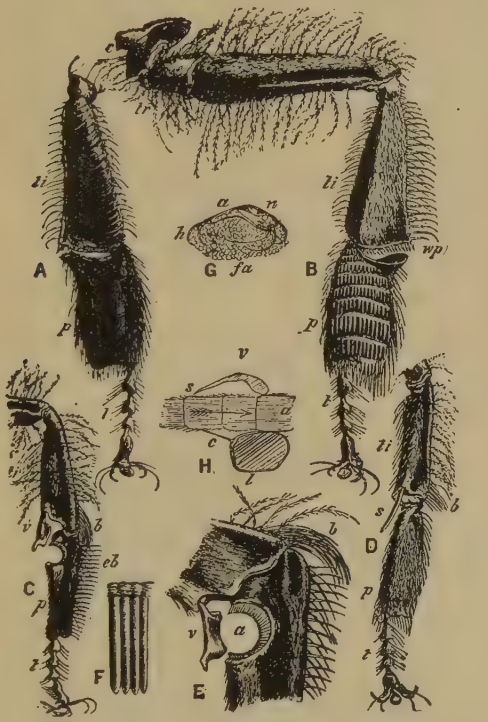


Fig. 232.

Legs of worker honey-bee. *A.*, outer side of metathoracic leg. *p.*, metatarsus; *t.*, tarsus; *ti.*, tibia. *B.*, inner side of metathoracic leg. *c.*, coxa; *p.*, metatarsus; *t.*, tarsus; *ti.*, tibia; *tr.*, trochanter; *wp.*, wax pinchers. *C*, prothoracic leg. *b.*, pollen brush; *eb.*, eye brush; *p.*, metatarsus; *t*, tarsus *ti*, tibia; *v.*, velum. *D.*, mesothoracic leg; lettering as in *C*. *s.*, pollen spur. *E.*, joint of prothoracic leg; lettering as in *C*. *F.*, teeth of antenna comb. *G.*, transverse section of tibia through pollen basket. *fa.*, pollen; *h.*, holding hairs; *n.*, nerve. *H.*, antenna in process of cleaning. *a.*, antenna; *s.*, antenna comb; *l.*, section of leg; *s.*, scraping edge of *v.*, velum. (From Root, after Cheshire.)

The **labium** lies medially and extends downward from beneath the labrum and is quite complicated. The **sub-mentum**, which is triangular in shape, joins the labium to the back of the head. The **mentum** lies next to the sub-mentum. The mentum is chitinous and contains muscle. The tongue, or **ligula**, lies immediately beyond the mentum. The tongue has a spoon-shaped end known as a **bouton**. A **labial palpus** lies at each side of the tongue, while tiny hairs, used as organs of taste and touch, as well as for gathering nectar, are arranged in regular rows upon it.

The lower jaws or maxillae extend over the mentum on both sides. There are stiff hairs on their edges, and **maxillary palpi** on each side.

The thorax is divided into **prothorax, mesothorax,** and **metathorax** (Fig. 213), the last two divisions each supporting a pair of wings, while hairs, which are used in gathering pollen, cover the outside of the entire thorax.

The legs of the bee are highly specialized (Fig. 232). The **prothoracic legs** have both femur and tibia covered with **branched hairs** which are used in gathering pollen. A **pollen brush** made up of curved bristles is seen at the distal end on one side of the tibia. This brush is used to brush up the pollen which has been loosened by some of the coarser spines.

On the other side of the tibia, a flat movable spine known as the **velum,** fits over a curved indentation in the first tarsal joint. The whole structure, brush and velum, is known as the **antenna cleaner,** while the row of teeth lining the indentation is called the **antenna comb.**

The antennae are cleaned by being pulled through the indentation between the teeth and the edge of the velum.

On this first tarsal joint also there is found a row of spines called the **eye brush.** This structure is used to brush out pollen which has lodged about the compound eyes.

On the last tarsal joint of each leg there is a pair of notched claws by which the insect holds on to rough surfaces. Between these claws there is a fleshy, glandular **lobule** known as the **pulvillus,** which is covered with a sticky secretion from the glands. It is by this sticky substance that the insect can attach itself to smooth surfaces. Then, too, there are **tactile** or touch hairs present.

The **mesothoracic legs** do not have an antennae cleaner, but at the distal end of the tibia there is a **spur** which is used to pry the pollen out of the pollen baskets on the third pair of legs, as well as to clean the wings.

The **metathoracic legs** are probably the most interesting, in that they possess **a pollen basket, a wax pincher,** and the **pollen combs.** The pollen basket is a concavity in the outer surface of the tibia. There are rows of curved bristles along the edges. Pollen is stored in this basket. The filling takes place by the pollen combs scraping out the pollen from the hairs on the thorax into the basket on the opposite leg.

The **wax pinchers** consist of a row of **wide spines** located at the distal end of the tibia. These lie in opposition to a smooth plate on the proximal end of the metatarsus. The pinchers remove the wax plates from the abdomen of the worker.

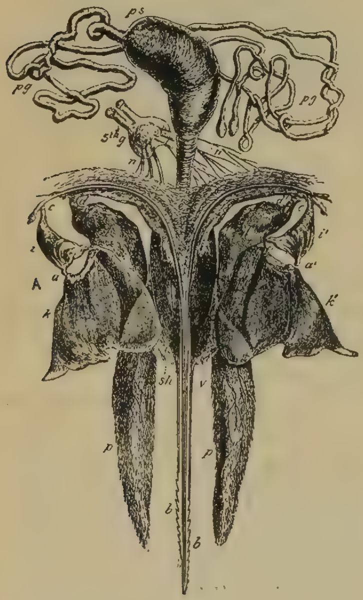


Fig. 233.

Sting of worker honey-bee. *b.*, barbs on darts; *i.*, *k.*, *l.*, levers to move darts; *n.*, nerves; *p.*, sting-feeler; *pg.*, poison gland; *ps.*, poison sac; *sh.*, sheath; *5th g.*, fifth abdominal ganglion. (From Packard, after Cheshire.)

As already stated, a pair of membranous wings are attached to **mesothorax and metathorax.** There are **hollow ribs** called **nerves** or **veins** passing through each wing. Often a row of little **hooklets** on the anterior margin of the hind wing is inserted into a trough-like fold in the posterior margin of the fore wing and thus join them together.

The abdomen is made up of six segments, each segment consisting of a **tergum or dorsal plate,** and **sternum or ventral plate.** A pair of **wax glands** is located on each of the four hindermost sternal plates. Both queen and worker possess a **sting** (Fig. 233) at the end of the abdomen, while the drone possesses a copulatory organ instead. There are also slit-like openings of the reproductive system and an anal opening in queen and worker.

The sting has a pair of **sting feelers** by which the bee seems to choose a favorable location for the deposit of the sting. Two barbed **darts** are then sent out. There is a **sheath** which guides the darts and aids in conducting the poison. The poison is secreted in a pair of glands, one acid and one alkaline, and it is then stored in a **reservoir.** It is commonly believed that if a bee stings, it dies. This is not necessarily true; but, very often a part of the intestine and the poison glands are pulled out of the body with the sting, and then, of course, the insect cannot live.

Queens usually do not sting except in combat with other queens.

INTERNAL ANATOMY AND PHYSIOLOGY

THE DIGESTIVE SYSTEM

Beginning at the anterior end, the digestive system (Fig. 234), is made up of **mouth, oesophagus or gullet, honey-sac or honey-stomach, true stomach, small intestine or ileum,** and **large intestine or colon.**

The oesophagus passes through the thorax and is expanded into a honey-sac at the anterior end of the abdomen. A **stomach-mouth** with four triangular lips is found at the posterior portion of the honey-sac. A number of bristles extends backward from the top of the lips. If the alimentary canal be placed in a one-half of one per cent salt solution immediately after the bee is killed, these lips will open and close for about thirty minutes. Both circular and longitudinal muscles surround the lips.

The glands in the walls of the stomach secrete digestive juices which change the food into chyme. Part of this is absorbed and part forced back into the ileum by muscular contractions. Here undigested food is dissolved and also absorbed, while that which is not digested is thrown into the colon, and from here, out of the body. No faeces are deposited in the hive if bees are kept in proper condition.

Two pairs of salivary glands may be found: one pair within the head lying against the cranium, and one pair in the ventral portion of the anterior half of the thorax. The substances secreted from these glands are weakly alkaline and are poured out upon the labium. Here they act on the food as it is ingested.

THE CIRCULATORY SYSTEM

The blood of the honey bee is quite like that of the crayfish and grasshopper, as it is colorless and contains amoeboid corpuscles. Little, if any, oxygen is contained within it.

The crayfish is also like the bee in that it has **a dorsal blood vessel and many sinuses,** but the bee's circulatory system is even less complete than that of the crayfish.

The **heart, or dorsal vessel,** is a tube in the median dorsal region just below the surface, closed posteriorly and open in the head-region. The walls being muscular, the heart contracts at intervals.

The blood itself enters through **five pairs of ostia,** one into each of the five compartments into which the heart is divided. Each compartment is called a **ventricle.** Each contraction sends the blood toward the heart. There are valves which prevent it from flowing backward. It then passes through the various spaces in the body to bathe the tissues. As the blood passes ventrally, it is gathered into the **pericardial sinus,** and when the muscles surrounding this sinus contract, the blood is forced through the ostia back into the heart when it is again ready to be sent out.

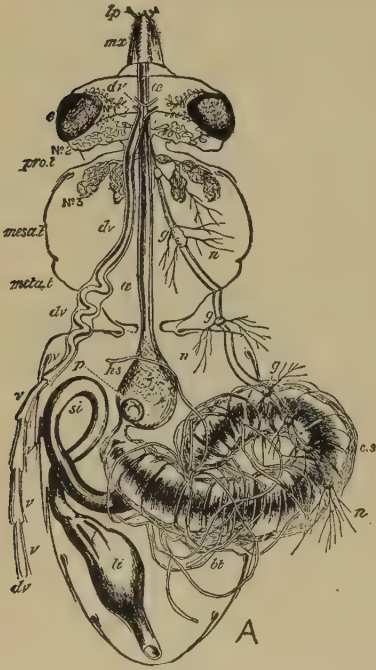
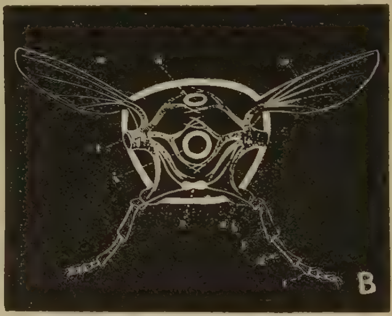


Fig 234.

A. Internal organs of the honeybee. *bt.*, malpighian tubules; *c.s.*, true stomach; *dv.*, dorsal vessel; *e.*, eye; *g.*, ganglia of nerve chain; *hs.*, honey sac; *li.*, rectum; *lp.*, labial palpus; mesa. *t.*, mesothorax; meta, *t.*, metathorax; *mx.*, maxilla; *n.*, nerves. No. 1, No. 2, No. 3, salivary glands; *oe.*, oesophagus; *p.*, stomach mouth; *pro.t.*, prothorax; *si.*, small intestine (ileum); *v.*, ventricles of dorsal vessel.



B. Ideal transverse section of an insect. *h.*, dorsal vessel; i., intestine; *n.*, ventral nerve-cord; *t.t.*, stigmata leading into the branched tracheal tubes; *w.w.*, wings; *a.*, coxa of one leg; *b.*, trochanter; *c.*, femur; *d.*, tibia; *e.*, tarsus. (After Packard, A, from Cheshire.)

THE RESPIRATORY SYSTEM

Along each side of certain thoracic and abdominal segments there appear openings called **spiracles** (Fig. 215). It is through these openings that the bee breathes. One pair of these spiracles may be found in the prothorax, one pair in the metathorax, and five pairs in the abdomen.

The spiracles open into little tubes known as **tracheae** which unite in turn with other tubes running in a longitudinal manner. These longitudinal tubes are called **the trunks,** and from the trunks many branches are given off to all parts of the body. The tracheary tubes (though only one cell in thickness) have thickened rings arranged spirally, and it is these rings which keep the tubes open.

Air-sacs are found in the abdominal region. These are expanded portions of the tracheae and probably make the bee lighter as it flies, for the bee can apparently increase and decrease the size of the air-sacs at will. There are tiny valves in the spiracles and the bee takes in and expels air by expansions and contractions of its abdomen. Hairs surround the spiracles so as to prevent dust from entering. The rate of respiration increases with the fatigue of the insect. Air is carried directly to the tissues through the tracheae so that no lung system is needed in which blood and oxygen must mix.

THE EXCRETORY SYSTEM

There are **Malpighian or urinary tubules** (Fig. 234, A) which are long, fine, hair-like structures, opening into the anterior end of the intestine. These are the excretory organs. Excretions are taken from the blood in the form of urates, and pass through these urinary tubules to the intestine from whence they are thrown out of the body with the faeces.

THE NERVOUS SYSTEM

The nervous system (Fig. 214, 235) of the bee is made up of a **chain of paired ganglia** with **two groups of smaller ganglia.** The first are called the **stomatogastric** and the latter the **sympathetic ganglia,** respectively. These ganglia are made up in turn of seven masses of nerve tissue: two in the head, two in the thorax, and five in the abdomen.

Each mass is composed of two ganglia which lie side by side, and these ganglia are connected with the mass in front and behind by two **nerve cords.** Only the brain (the most anterior pair of ganglia) also called the **supraoesophageal ganglia,** lies dorsal to the digestive tract.

The compound eyes, **the ocelli,** the antennae, and the labrum, are connected with the brain by nerve twigs, while the mandibles, labium, and other mouth-parts are connected with the **suboesophageal ganglion** lying directly beneath the oesophagus.

The most anterior ganglia in the thorax innervate the muscles of the first pair of legs, while the posterior thoracic ganglion is larger and composed of several ganglia which have grown together. From the fore part of this latter ganglion, nerves run to the fore wings and middle pair of legs, while twigs from the posterior portion of this same ganglion pass to the hind wings and legs.

The organs and walls of the abdominal region are supplied by twigs from the various abdominal ganglia; but, as with most animals, the more posterior abdominal ganglia are the larger.

The stomatogastric portion of the nervous system is composed of many small ganglia which are in direct connection with the organs of digestion, circulation, and respiration, while the sympathetic nervous

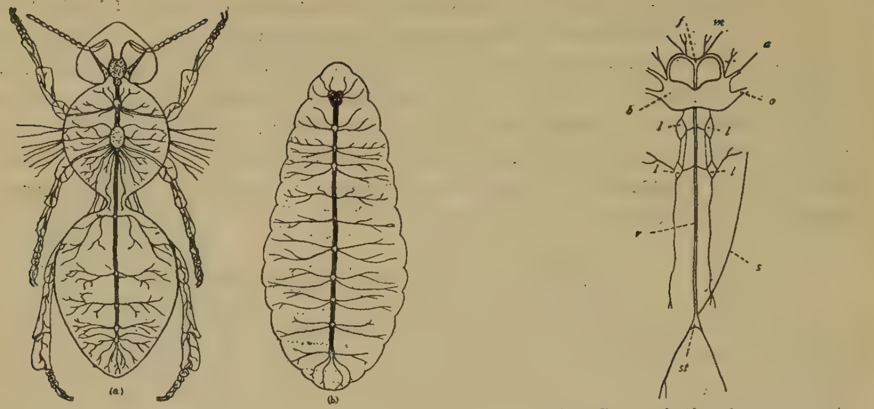
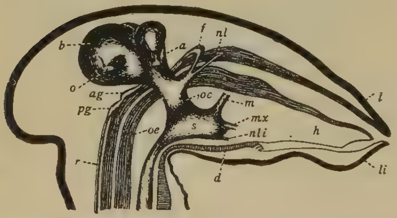


Fig. 235.

A. Nervous system of honey-bee, at *a.*, and of its larva, at *b.*, showing the simple type of the larva and the specialization in the adult due to fusion of the ganglia. (From Sanderson and Jackson, "Elementary Entomology," by permission of Ginn & Co.)

B. Sympathetic nervous system of an insect, diagrammatically represented. *a.*, antennal nerve; *b.*, brain; *f.*, frontal ganglion; *l.l.*, paired lateral ganglia; *m.*, nerves to upper mouth-parts; *o.*, optic nerve; *r.*, recurrent nerve *s.*, nerve to salivary glands; *st.*, stomachic ganglion. (After Kolbe.)



C. Nervous system of the head of cockroach. *a.*, antennal nerve; *ag.*, anterior lateral ganglion of sympathetic system; *b*, brain; *d.*, salivary duct; *f.*, frontal ganglion; *h.*, hypopharynx; *l.*, labrum; *li.*, labium; *m.*, mandibular nerve; *mx.*, maxillary nerve; *nl.*, nerve to labrum; *nli.*, nerve to labium; *o.*, optic nerve; *oc.*, oesophageal commissure; *oe.*, oesophagus; *pg.*, posterior lateral ganglion of sympathetic nervous system; *r.*, recurrent nerve of sympathetic system; *s.*, suboesophageal ganglion. (After Hofer.)

system is made up of the many fibers which pass to all parts of the body from the triangular ganglia lying in each segment.

ORGANS OF SPECIAL SENSE

These have already been discussed very thoroughly under the general term, "The Senses of Insects," in Chapter XXIII.

THE MUSCULAR SYSTEM

As in the crayfish, the muscles of the honey bee are attached to the inner walls of the body. The number of muscles is very large, and the largest muscles are those which move the wings and legs.

Muscles are both voluntary and involuntary. A good example of the latter has already been noted in the experiment suggested of the intestine being placed in a one-half of one per cent salt solution when the lips of the stomach-mouth will open and close for some time.

Insects usually have much greater muscular strength proportionately than larger animals. This is accounted for by the fact that the weight of muscle increases as the cube of its diameter, while its strength increases only as the square of its diameter.

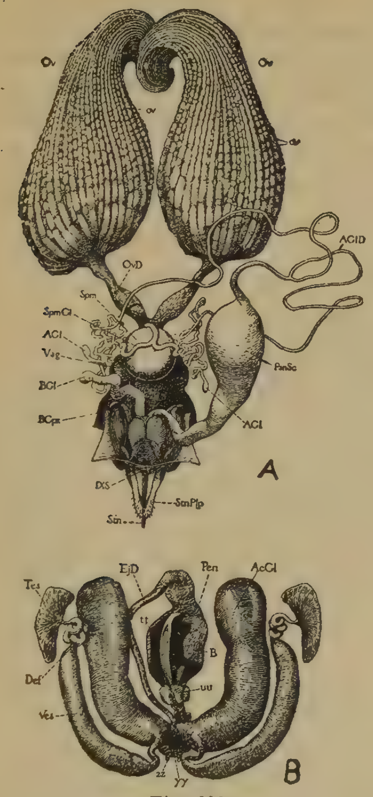


Fig. 236.

A. Reproductive organs, sting, and poison gland of queen honey-bee. *AGl.*, acid gland; *AGlD.*, duct of acid gland; *BGl.*, alkaline gland; *Ov.*, ovary; *ov.*, ovarian tubules; *Ov.D.*, oviduct; *Psn.-Sc.*, poison sac; *Spm.*, spermatheca; *Stn.*, sting; *StnPlp.*, sting feeler; *Vag.*, vagina.

B. Reproductive organs of drone bee, dorsal view, natural position. *AcGl.*, accessory gland; *B.*, bulb of penis; *EjD.*, ejaculatory duct; *Pen*, penis; *Tes.*, testis; *vDef.*, vas deferens; *Ves.*, seminal vesicle; *tt.*, *uu.*, *yy.*, *zz.*, parts of penis. (From Snodgrass, Tech. Series, 18, Bur. Ent., U. S. Dep't. of Agric.)

THE REPRODUCTIVE SYSTEM

Only the queen (Fig. 236, A) can lay eggs, although the workers have rudimentary ovaries.

The **two ovaries** almost fill the abdomen of the queen. Each of the ovaries is made up of a great number of **ovarian tubules** which contain eggs of different sizes. The eggs pass into the **oviduct** from the tubules, thence into the vagina and out of the body through the **genital aperture.**

There is an opening into the vagina which connects with the **spermatheca** or sac in which the sperm are stored, and sperm from this sac may apparently be released at will by the queen as the eggs pass through. If the sperm is not released the egg is not fertilized and then drones hatch. Only females hatch from fertilized eggs.

In the drone (Fig. 236, B) **two testes** are seen which are made up of several hundred **spermatic tubules** in which the sperm are formed. A pair of fine tubes called **vasa deferentia** connect these spermatic tubes with the **seminal vesicles.** These latter in turn open into a pair of large mucous glands which unite. It is at this union that the **ejaculatory duct** begins. This duct ends in the copulatory organ.

The sperm of the male are placed in the **spermatheca** (seminal receptaculum) of the queen by a single drone, where they remain alive for many years, in fact as long as the queen lives and lays eggs. While the average life of a queen is probably somewhere around three to four years, there is on record a queen which continued laying fertile eggs for thirteen and a half years.

About five to eight days after emerging from the egg, a queen will leave the hive. First, she crawls about and takes very short flights, and then goes on a **nuptial trip** of about thirty minutes. One of the drones copulates with her during the nuptial trip, after which the queen returns

The eggs are bluish-white and oblong in shape. They are fertilized just before leaving the queen's body. The eggs are deposited at the base of the cells and then fastened into position in the cells by a secretion. Fertilized eggs are laid in cells that have already been arranged to receive them, some being in **queen cells,** and some in **worker cells,** while unfertilized eggs are placed in **drone cells.** But there seems to be evidence that mistakes are made, and the right type of egg is not always placed in the right cell.

EMBRYOLOGY

After the nuclei of the sperm and egg have united into a single nucleus a chitinous covering, **the chorion,** surrounds the entire egg. As cleavage takes place, no definite cell walls appear. This means that a great mass of protoplasm is present with many nuclei. These nuclei migrate to the periphery to form a single layer of cells, called the **blastoderm,** while the remaining portion of the yolk remains as yolk-substance until it is converted either into food for the developing embryo, or into further cellular substance.

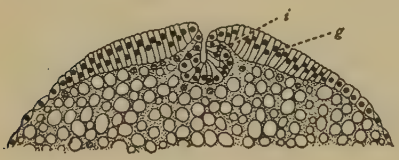


Fig. 237.
Cross section of germ-band of *Clytra* at gastrulation. *g.*, germ-band; *i.*, inner layer. (After Le'caillon.)

A **germ-band** or **primitive streak** (Fig. 237) now forms on one side of the egg where the blastoderm becomes thickened. This is to become the ventral side of the bee. The brain develops separately. A median groove arises in the germ-band, and so two germ layers are formed, an outer layer called the **ectoderm,** and an inner known as the **entomesoderm.** It is the latter layer from which both entoderm and mesoderm arise. Now the germ-band grows around the entire egg.

It is of interest to know that while the antennae and four pair of appendages can be seen near the anterior end of the embryo, one pair of the anterior appendages disappear and the others become mouth parts. Then, three pair of appendages develop on the thorax, all of which disappear before hatching.

METAMORPHOSIS

The life-history of the bee is divided into four periods: **egg, larva, pupa,** and **adult or imago.**

Queens, workers, and drones remain in the egg three days, but the queens remain in the larval stage five and a half days, and in the pupal stage seven days, while the workers remain in the larval stage five days, and in the pupal stage thirteen. The drones remain in the larval stage six days, and in the pupal stage fifteen days.

During the fourth day the larva hatches from the egg as a white, footless, soft, grub-like form floating in "bee-milk," also called "royal jelly." This "milk" is composed of digested honey and pollen with probably some glandular secretions. The "milk" is formed in the true stomachs of special "nurse" workers who place it in the cells.

All larvae are fed this royal jelly for about three days by the nurse workers, but then a change takes place. Those which are to become workers are fed honey and digested pollen, while those which are to become queens alone continue to get the richer royal jelly until they change to the pupal stage. The drone larvae, after the fourth day, receive undigested pollen and honey.

The young larvae grow rapidly and shed their exoskeleton several times. In fact, during the last molt, even the lining of the alimentary canal and all its contents is shed with the exoskeleton.

Some five or six days after hatching, the nurse worker places a quantity of food in the cell with the larva and places a cap on the cell. The larva spins a cocoon of silk about itself some two or three days later. It is now in a resting stage and is called the **pupa.**

The spinning-glands are in the mouth region, and later become the salivary glands of the adult.

Almost the entire structure is made over during this pupal stage and the full-fledged bee emerges in its adult form and shape.

BEHAVIOR

As the queen emerges from the pupal stage the eggs have not yet distended her abdomen, so she is about the same size as a worker. As soon as she becomes accustomed to her surroundings she starts on a hunt for other queen cells. She breaks through these and stings the pupa within or tears the cell down and lets the workers remove such destroyed structures with the other debris. There is thus only one queen left. It is after this time that the nuptial-flight, already mentioned, takes place. By the ninth or tenth day she is busy laying eggs. The number of eggs laid, or at least the rapidity with which eggs are laid, is determined by the amount of food the workers bring home. More eggs are laid when more food is obtained.

The workers, when young, act as nurse maids for a week or two before taking up the regular duties of gathering food. Some of these also defend the hive against outside attacks, clean the hive, and even go scouting to find suitable new quarters before swarming.

The workers really work themselves to death, and probably live only some five or six weeks. New ones are being hatched continually to keep the normal number of bees in the hive. Those which hatch in the fall may live five or six months.

If a queen should die, any one of the workers may with proper feeding, be able to develop and lay eggs, but in such cases the new queen would not have had the nuptial-flight, and therefore no eggs would be fertile. Consequently drones alone are hatched from the eggs.

Drones hatch in the same way that queens and workers do, but take no part in the work of the hive. One of them alone acts as queen-consort. As soon as food is scarce they are starved to death and their dead bodies removed with the remaining debris. At such a time even the drone pupae, larvae, and eggs are destroyed.

As new bees are constantly being hatched, the hive may become overcrowded. When this occurs it is the old queen which collects several thousand bees about her and goes through a complicated preparation to start a new colony. Scouts are sent out to seek a fitting location, and after first settling on a tree-branch or other object in a very dense cluster, the whole colony takes up its new abode.

The cells are made of wax. Those which are to have eggs placed in them are hexagonal in shape, although a careful examination will show they all vary slightly from each other. The cells which are to contain honey are rounded.

The wax is produced by a secretion from the smooth, paired patches called **wax-glands** on the ventral surface of the abdominal metameres. The process gone through is as follows: The bees gorge themselves with honey. Great clusters of such bees then hang from the top of the hive for several hours when thin scales of wax form on the plates. These scales of wax are then removed by the hind legs, while the fore-legs transport it to the mouth. Here the wax scales are mixed with saliva and kneaded by the mandibles. The wax is then ready either to repair old cells or build new ones.

The cells may be built especially for honey or for breeding, but often drone cells, even when the cocoon is still present, are used for honey cells. However, cells made especially for honey have the openings somewhat above their bases so that the honey will not run out.

The cells which fasten the comb to the top and sides of the hive are called **attachment cells.**

Bees gather **nectar** (not honey) from flowers. The maxillae and the labial palpi form a tube through which the tongue can move backward and forward. As the epipharynx is lowered, a definite passage connects this tube with the oesophagus. The nectar itself becomes attached to the hairs on the tongue, and is forced upward by pressing maxillae and palpi together. It is then swallowed into the honey-sac, where the necessary chemical changes which convert it into honey take place. Here it is retained until the bee reaches the hive, when it is regurgitated into the cells made to receive it. As there is much water contained in the newly-formed honey, the cells are left open until the water is considerably evaporated. This is called the "ripening process." When the honey is "ripe" the cell is capped with wax.

The bees keep their wings moving while in the hive both to keep air circulating and (in winter) to produce heat.

About thirty to fifty pounds of honey are produced a season by one hive if conditions are favorable.

As honey lacks proteins, bees gather pollen by means of their mouth parts and legs, and mix it with either saliva or even nectar to make it sticky. It is then placed by the hind legs in the pollen baskets. As the bee enters the hive, it backs up to a cell in which a larva is placed, and scrapes the pollen into such cell by aid of the **spur** already mentioned. The deposited substance is known as "bee-bread." The young workers then pack this bee-bread into the cells by using their heads as tampers.

Still another substance known as **propolis** or **"bee-glue"** is gathered by bees for the purpose of filling up cracks, for strengthening weak parts, or even, probably, as a sort of varnish. Propolis is merely the resinous material gathered from various plants which is then inserted into the pollen basket. In the case of propolis, another worker removes it from the gatherer, and it is this other worker which also applies it where needed.

In warm, dry weather, water is often sucked into the honey-sac from dew, brooks, or ponds, and then carried to the larvae in the hive. In cool weather enough water usually condenses in the hive. In fact, so much moisture may condense as to injure the occupants.

All debris is removed immediately, so that cleanliness is insured.

ENEMIES OF THE HONEY BEE

There is a Bee-Moth, **Galleria mellonella,** which, when it can find an entry, lays its eggs in the hive. The larvae then feed on pollen cocoons and even cast-off larval skins. They burrow into the comb and line their burrow with a silk which protects them from the bees, much as a spider's web can either keep out or entrap insects.

There are also bee-lice which attach themselves to the queen and weaken her by sucking the juices from her body. The bee lice, while common along the Mediterranean Sea, are uncommon in America. Spiders often catch bees in their webs.

Other insects such as dragon-flies, ants, and wasps may attack bees. Toads and lizards also attack them, but these latter can be removed to some distance from the hive and will then serve the important function of devouring really noxious insects.

Mice prey upon pollen, honey, and even bees in the winter time. One may note here, as we have already noted in the relation of insects to man, that there may be various ways of insuring a "balance in nature." As cats devour mice, and mice bees, the number of cats may be the deciding factor of the number of bees there are in a given neighborhood. In fact, Huxley even suggested that this idea could be carried still further by considering the number of old maids who were fond of cats, these cat lovers then becoming the deciding factor as to the number of bees a given region might have.

Various diseases afflict bees, probably largely of a bacterial nature brought about by too long confinement in the hive. Once a disease has taken hold of a hive it may infect any or all other hives in the region.

GYNANDROMORPHS

It has been found that among butterflies, ants and bees, it is not uncommon to have an abnormal individual which has male characteristics in one part of its body and female characteristics in another. The term **gynandromorphs** (Fig. 238) has been given such individuals. The more common form such gynandromorphs assume is that of the anterior part of the body being one type and the posterior another, or the entire right side may be of one sex and the entire left side another.

Bees are particularly valuable in bringing about cross fertilization of flowers. In fact, the **Bumble Bee** is about the only insect visiting red clover which has its mouth parts long enough to reach down for the nectar of that plant, so that if it were not for the bumble bee, red clover would probably not grow at all.

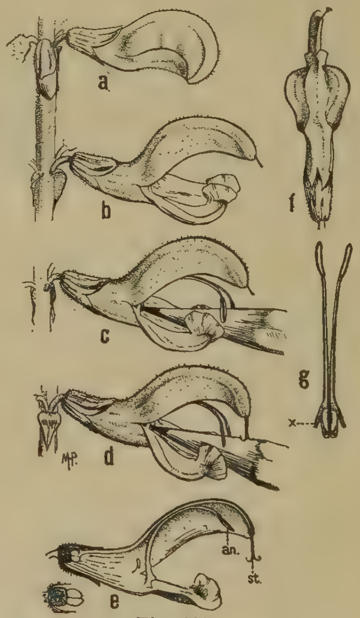


Fig. 239.

Salvia sp. (One of the Labiatæ). *a.*, flower bud; *b-f.*, various views of the open flower; *an.*, anther; *st.*, stigma; *x.*, projections near the base of the filaments. The lead pencil is made to imitate an insect visiting the flower for pollen. By pressure at the base of the filaments, the anthers are brought into contact with the surface of the pencil, which thus becomes covered with pollen. When the next flower is visited the stigma, having then bent down and spread apart, receives the pollen from the other flower. Thus is accomplished cross-pollination. In *b.*, before the visit of the insect, the stigmatic surfaces are still in contact, so that pollination is not possible. (From C. Stuart Gager's "Fundamentals of Botany" by permission of P. Blakiston's Son & Co., Publishers.)

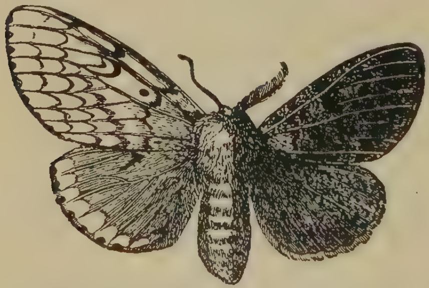


Fig. 238.
External appearance of gynandromorph. Lateral hermaphroditism of gypsy moth. Left side female; right side male. (After Taschenberg.)

Orchards which have hives of bees usually show a better harvest of fruit than those without hives.

It is probably color, odor, and the structure of both insect and plant which determine which plants are visited most.

Many plants are so constructed that an insect entering the flower for nectar comes in contact with the pollen of the plant which thus brushes off on the insect's back (Fig. 239). Then as another flower is visited this pollen is brushed off by the stigma thus bringing about fertilization.

CLASSIFICATION

The Summary of the Arthropoda will show under what phylum, class and order bees are classified. But here it is necessary to mention the following five types of honey bees found in the United States, though none are native.

German, with black-colored abdomen. These are the so-called wild honey bees.

Italian, with yellow-striped abdomen.

Carniolan, with gray abdomen.

Cyprian, with yellow abdomen.

Caucasian, with yellow-gray abdomen.

All bees are included in the great family **Apidae,** but there are both solitary and social species. Then, too, some are miners, carpenters, leaf-cutters, etc.

As different species of bees have different length of tongues their food must vary accordingly. This was seen in our discussion of the Bumble Bee, which alone of all the bees, has a long enough tongue to obtain the nectar from red clover. Short-tongued bees must seek a flower with a less deeply placed nectar.

The list of books at the end of this chapter will furnish many chapters of interest as to the more detailed life and habits of all species of bees.

THE FLY

As flies may carry "tuberculosis, cholera, enteritis (including epidemic dysentery and cholera infantum—the fly-time 'summer complaint' of infants), spinal meningitis, bubonic plague, smallpox, leprosy, syphillis, gonorrhea, ophthalmia, and the eggs of tapeworms, hookworm, and a number of other parasitic worms," they are certainly worthy of our attention, and should be thought of here, although it must not be thought that flies are the only carriers of these diseases. This is especially interesting when it is noted that while only about two persons die each year in the United States from the bites of poisonous snakes, about one hundred from the bites of rabid dogs, nearly 100,000 die annually from diseases carried by flies.

There are more than 43,000 different kinds of flies, gnats and mosquitoes which have been described in entomological literature, and there is no telling how many more are still unknown. Tachina flies (Fig. 240), already described as killing grasshoppers, and **Syrphus flies** ( ) feed on insects and are therefore of value to man, but nearly all others should be exterminated. Over ninety per cent of the flies found in and about homes are the regular typhoid flies. When it is remembered that the feet of these are furnished with claws for climbing over rough surfaces as well as with two pads, the **pulvilli**, covered with sticky, tubular hairs by which the animal can attach itself to ceilings and glass surfaces, one can understand the excellent summing up of what this means—that "No more effective mechanisms for collecting dust could be designed than a fly's feet and proboscis (Fig. 216), a combination of six feather dusters and thirteen damp sponges. While the constant 'cleaning' movements of flies are clearly designed to rub off and scatter the adhering germs everywhere they go."

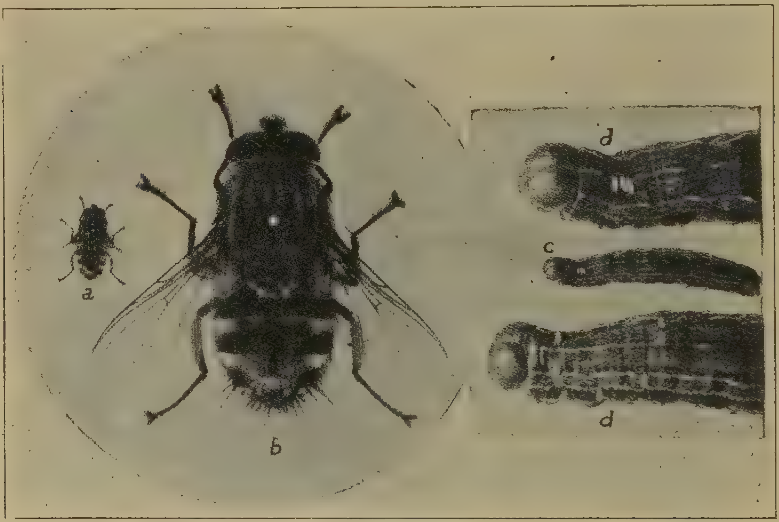


Fig. 240.

The Friend of Farmers. Red-tailed tachina-fly (*Winthemia 4-pustulata.*) *a.*, natural size; *b.*, much enlarged; *c.*, army worm on which fly has laid eggs, natural size; *d.*, same, much enlarged. (After S. Singerland.)

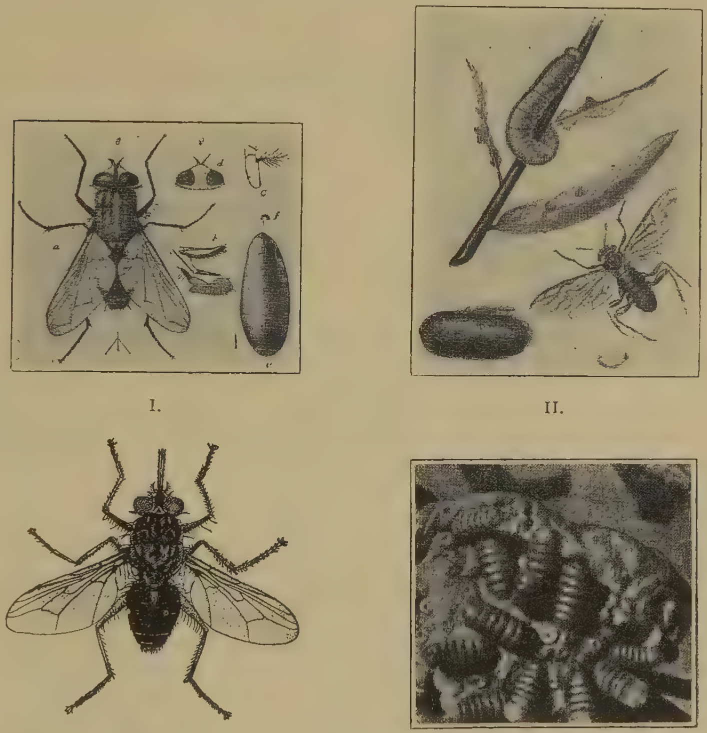
There are "little house flies" **(Fannia canicularis)** which probably most people believe grow into the regular house fly. Their breeding habits and feeding places are quite similar to the house fly, **but**, as **flies hatch in the adult form they do not grow after once becoming flies.**

Other flies such as **bluebottles, greenbottles,** and **flesh flies** or **blowflies** are also found about the home and frequently lay their eggs on meat. These flies are scavengers.

In the South there is the screw-worm fly **(Chrysomyia macellaria)** which deposits its eggs on wounds, for the maggots of this species feed on living flesh. It is these flies also which are likely to lay their eggs in the nostrils and ears of children or even of adults as they sleep out of doors. The maggots then cause intense pain as they feed on the surrounding flesh.

The stable fly **(Stomoxys calcitrans)** looking something like a housefly, except that it has a strong piercing beak, sucks blood from animals. It is supposed to be the animal which carries the germs of infantile paralysis in addition to the injury it causes cattle.

The smaller horn fly **(Haematobia serrata)** swarms about the bases of the horns of cattle, biting constantly.



I. II. III. IV.

Fig. 241.

I. Typhoid fever or house-fly (*Mus'ca domes'tica*:) *a*, Adult male; *b*., proboscis and palpus of same; *c*., terminal joints of antennæ; *d*., head of female; *e*., puparium; *f*., anterior spiracle; all enlarged. (Howard and Marlatt, Bull. U. S. Dept. of Agriculture, 1896.)

II. Metamorphosis of Saw-Fly.

III. Tsetse fly, which causes a disease of cattle in Africa, enlarged. (L. O. Howard.)

IV. Larvæ of bot flies attached to the walls of the stomach of a horse. (After Osborn.)

LIFE HISTORY

Flies (Fig. 241) breed about filth, and any decaying matter, though they can breed and do in any wet, fermenting vegetable or animal matter. The maggots are hard to kill; they will live in pure kerosene for over an hour, and even more than thirty minutes in alcohol. They have even been bred from the open boxes of snuff on a druggist's counter, though tobacco is supposed to be quite injurious to insects.

After the housefly's eggs are laid it takes about **eight hours for them to hatch into maggots.** These finish their growth in **six to seven days,** burrowing into the ground "under the manure pile" (hence the need of concrete floors) and transform into brown **puparia,** from which they emerge as **adult flies in three days.**

Hodge and Dawson have summed up the rapid increase in flies most tellingly in the following words:

"After coming out as adults they fly about over an area **not generally more than one thousand yards in diameter,** and feed and drink from two hundred to three hundred times a day **for from ten to fourteen days** before maturing their first batch of eggs. This actually delivers the enemy into our hands. It means that, with flytraps on every garbage can and swill barrel, and with everything most attractive to flies very carefully kept in these receptacles, not a single fly will succeed in feeding for two weeks without getting caught. In this case no more eggs will be laid, and the pests will vanish.

"Allowing ten days of feeding between emergence and oviposition, figuring that a fly lays one hundred and fifty eggs at a batch and lives to lay six batches, compute the increase of a pair of flies beginning to lay May 1. Half the progeny are supposed to be females. Test the following figures:

May 10	152 flies.
May 20	302 flies.
May 30	11,702 flies.
June 10	34,302 flies.
June 20	911,952 flies.
June 30	6,484,700 flies.
July 10	72,280,800 flies.
July 20	325,633,300 flies.
July 30	5,746,670,500 flies.

"As this last amount makes 143,675 bushels of flies resulting from **a single pair of flies in three months,** one can estimate what the result will be if allowed to breed unrestrained during August and September beside.

"The common sense question, then, is, why not let this pair of flies catch themselves in May? This rapid increase also means that anything short of extermination is hardly worth the effort. A fly is possessed of no more cunning than shot rolling down a board, and the last pair will run into a trap as easily as the first. Why not let them all catch themselves?"

During the winter, especially in cold climes, most of the flies are killed, but probably some maggots pass the winter underground and in stables where it is sufficiently warm, coming forth in the spring when the weather warms up.

It has often been assumed that burying debris of various kinds would kill the maggots. This is not true, as the maggots have crawled up through six feet of earth, with which they were covered.

The best method of handling debris, such as manure, is to spread it on the land daily. This is especially valuable, as manure loses almost half its fertilizing power if stored. The sun will dry it and this will also prevent the moisture which maggots need in order to thrive. However, if this cannot be done, then a solution of iron sulphate (copperas), two pounds to the gallon of water, may be thrown over such matter. Chloride of lime is expensive and the fumes (chlorine) are likely to injure the farm animals.

FLY KILLERS

The Kansas Board of Health Bulletin gives the following methods of killing flies:

"A cheap and perfectly reliable fly poison, one which is not dangerous to human life, is bichromate of potash in solution. Dissolve one dram, which can be bought at any drug store, in two ounces of water, and add a little sugar. Put some of this solution in shallow dishes and distribute them about the house."

"One of the best fly killers that can be used in the home is a teaspoonful of formalin in a quarter of a pint of water. When this is exposed in a room it will be sufficient to kill all flies. They seem to be fond of the water. Care should be taken to place it beyond the reach of children."

"To quickly clean a room where there are many flies, burn pyrethrum powder. This stupefies the flies, when they may be swept up and burned."

And the Agricultural Extension Department of the International Harvester Company suggests the following ointments and sprays to keep flies away from cattle:

(Any of the following must be applied frequently, as few will keep flies away for more than a day or two following their application.)

One pound rancid lard, ½ pint kerosene.

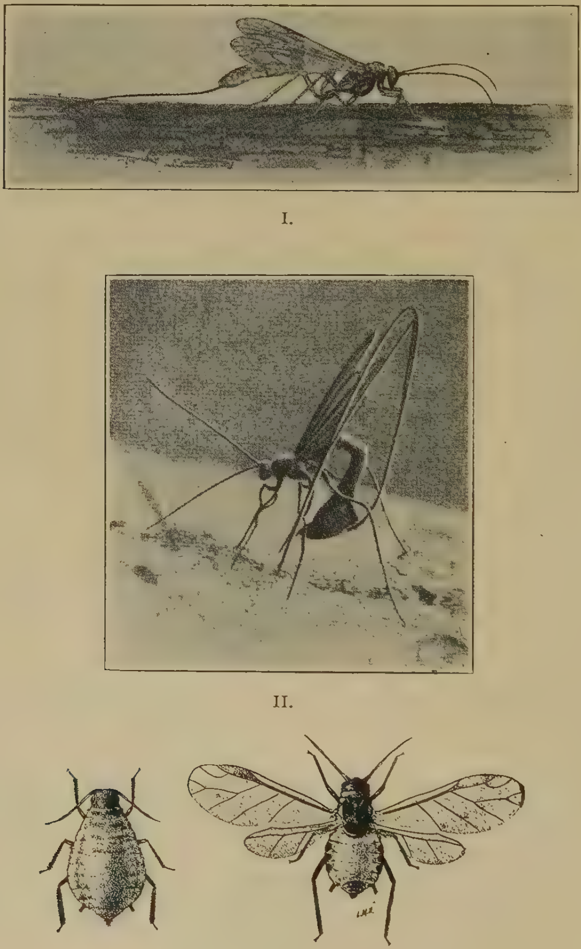
Mix until a creamy mass forms. Best applied with cloth or with bare hand. Rub thinly over the backs of the cows.

Three parts fish oil, one part kerosene. Apply with small spray pump.

Two parts crude cottonseed oil or fish oil, one pint pine tar. Apply with large paint brush.

PARASITIC INSECTS

"Among the insects there are many kinds that live parasitically for part of their life, and not a few that live as parasites for their whole life. The true sucking lice and the bird lice live for their whole lives as external parasites on the bodies of their host, but they are not fixed—that is, they retain their legs and power of locomotion, although they have lost



I.

II.

III.

Fig. 242.

I. Ichneumon-fly. Natural size.

II. Thalessa boring in an ash tree to deposit its eggs in the burrow of a horntail larva, a wood borer. From photograph, natural size. (After Davison.)

III. Corn root aphis (*Aphis maidiradicis*), winged and wingless female. The two black processes at the rear are *Cornicles*. (From Needham's "General Biology" by permission The Comstock Pub. Co.)

their wings through degeneration. The eggs of the lice are deposited on the hair of the mammal or bird that serves as host; the young hatch and immediately begin life as parasites, either sucking the blood or feeding on the hair and feathers of the host. In the order **Hymenoptera** there are several families, all of whose members live during their larval stage as parasites. We may call these hymenopterous parasites, **ichneumon** ( ) flies. (Fig. 242.) The ichneumon flies are parasites on other insects, especially of the larvae of beetles and moths and butterflies. In fact, the ichneumon flies do more to keep in check the increase of injurious and destructive caterpillars than do all our artificial remedies for these pests. The adult ichneumon fly is four-winged and lives an active, independent life. It lays its eggs either in or on or near some caterpillar or beetle grub, and the young ichneumon, when hatched, burrows into the body of its host, feeding on its tissues, but not attacking such organs as the heart and nervous ganglia, whose injury might mean immediate death to the host. The caterpillar lives with the ichneumon grub within it, usually until nearly time for its pupation. In many instances, indeed, it pupates with the parasite still feeding within its body, but it never comes to maturity. The larval ichneumon fly pupates either within the body of its host or in a tiny silken cocoon outside of its body. From the cocoons the adult winged ichneumon flies emerge, and after mating find another host on whose body to lay their eggs."

As an example of a parasite living upon another parasite, though one of these uses a tree as its host, the remarkable ichneumon fly **Thalessa** (Fig. 242) is an excellent example. This animal, which has a very long, slender, flexible ovipositor, finds a spot in a tree where the insect **Tremex columba** ( ), commonly called the **pigeon horntail,** has deposited its eggs about a half inch below the surface of a growing tree. When these eggs are converted into larva, the larva digs still deeper into the tree, filling up the open space behind it with tiny chips. Through a very extraordinary instinct the **Thalessa** finds the spot opposite where the **Tremex** larva lies and "elevating her long ovipositor in a loop over her back, with its tip on the bark of the tree, she makes a derrick out of her body and proceeds with great skill and precision to drill a hole into the tree. When the **Tremex** burrow is reached she deposits an egg in it. The larva that hatches from this egg creeps along this burrow until it reaches its victim, and then fastens itself to the horntail larva, which it destroys by sucking its blood. The larva of **Thalessa,** when full grown, changes to a pupa within the burrow of its host, and the adult gnaws a hole out through the bark if it does not find the hole already made by the tremex."

Practically all the **mites** ( ) and **ticks** ( ), animals closely allied to the spiders, live parasitically.

Truly Dean Swift was right when he said:

"Great fleas have little fleas
Upon their backs to bite 'em,
And little fleas have lesser fleas,
And so ad infinitum."

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CHAPTER XXV.

THE HISTORY OF BIOLOGY

It is generally conceded that those who have been with a business organization throughout its growth period know most about that business. Such men not only understand a thousand details of the work that others do not, but they know why they do what they do. The same truth holds good in science. But as none of us was present when science began, the only way we can obtain such an understanding is to read the story of those who were present; as a consequence, the history of any branch of science becomes an important study in the college curriculum.

In reading history we are always inclined to pass some sort of a judgment on the characters there found. This judgment is, however, quite likely to prove erroneous, unless we first know something of the times in which they lived, the obstacles they had to overcome, and the reasons they had for beginning work in new fields.

We must weigh the evidence on all sides of a question very carefully, so as not to confuse **conspicuousness with importance.** For example, an inventor is likely to be widely known because men at large can see, use, and understand his invention; but, as soon as another inventor improves, or brings about another apparatus which takes the place of the first invention, the first inventor ceases to interest men, and is then soon forgotten.

Such a state does not apply to the **real scientist—the discoverer of a new principle**—for, every invention and every application that his principle brings about in future time, proves that principle to be just so much the more important, and causes the scientist to be considered greater and greater through onflowing years.

It is therefore the real scientists, the true originators and discoverers of principles who must be known and honored.

First, then, let us try to catch a glimpse of the times in which men of past ages worked.

From the very earliest period of which we possess records, men have been interested in agriculture and medicine—which means, **botany** and **zoölogy.** Botany, in so far as a practical knowledge of food-plants was essential to successful agriculture, and in so far as a practical knowledge of medicinal plants was essential for the health of man and his animal servants. Zoölogy, in so far as a practical knowledge of the breeding of cattle and sheep was essential to a successful livelihood, and in so far as a knowledge of the human body was essential to prevent wounded men from bleeding to death.

Aristotle (384-322 B. C.), who was the pupil of **Plato,** was one of the first men to think of botany and zoölogy as a definite branch of study. His great contribution to biology was that **nature worked by definite fixed laws**—what we now call the **law of continuity.**

This discovery is intensely important because it made experimental science possible. There would be but little use in spending months and years in attempting to prove anything, if the laws of nature worked differently at different times, under the same conditions; for, the real value of experimenting is found in one's ability **to prophesy** that the same result will always take place if the same experiment is performed under the same conditions.

The first mark of a true scientist is accurate observation and perfect description, and the second is the power of visualization, by which he can build up and mold his interpretations into a **principle.**

Aristotle had a mind of the highest type, and so his generalizations still hold good after a lapse of thousands of years, provided, always, that his facts were correct. He did not have the instruments for accurate observation that we now have, so he often had to take many things for granted which have since been proved erroneous. But, his logic never failed him when his facts were right.

Theophrastus (370-286 B. C.) laid the foundations of botany. The astounding point that meets one in the reading of these old philosophers is that they were able to work out so great an amount of detail with the poor equipment they had, when we, with all our modern improved apparatus, must search most diligently before we can accomplish the same results.

As medical men were the first workers in biology proper, **Hippocrates** (460-370 B. C.), the Father of Medicine, must be mentioned. He made medicine into a separate science and set forth the ideals of the medical man which are still an inspiration to all.

Dioscorides (about 64 A. D.), an army surgeon under Nero, and **Galen** (131-201 A. D.), physician to Marcus Aurelius and his son Commodus, were both Greek physicians. The former originated the pharmacopoeia, which was the standard textbook of botany for some fifteen centuries. The latter wrote an anatomy and physiology which also was a standard textbook for medical students for the same length of time.

Pliny the Elder (23-79 A. D.) wrote a book which, although supposed to be accurate, had fact and fancy blended to so considerable an extent that it is hard to separate them.

The men mentioned above are the only biological workers of whom we have any record up to the time Christianity began to function.

The Roman Empire was mistress of the World at this time, and **pleasure** was the Roman ideal. Christianity strenuously opposed such an ideal, and soon won Emperor and people to its side. The moment this occurred, all efforts on the part of both student and soldier were directed toward performing such acts as would bring glory to the God they had accepted. And, as always, when the ideal of a nation is thrown aside, the pendulum swings completely over to the other side. Consequently, after Christianity was adopted, **suffering**, from having been considered a burden and a nuisance to men who held pleasure as their ideal, became something to be endured and practically enjoyed, inasmuch as he who suffered was thus imitating in some small measure the sufferings of the founder of Christianity. It follows that no great impetus was given to work that had for its object the relief of physical discomforts. At this time, also, barbarian hordes were a constant menace, and wars and rumors of wars not only kept men in the field, but forced all energy to be directed toward the end of setting up some kind of military and defensive stability. And, while many scientific applications are produced for destructive purposes in war, there can be no true science at such time. Little serious studious work can be accomplished unless there is leisure and freedom from danger.

At this time there were only two fields of work in which a youth of ambition might enter—the army and the Church. The first attracted men who sought physical power, while the second attracted those who sought knowledge.

The Church therefore established universities and libraries in the monasteries—the only place where one could find men interested in learning. It was here that the works of the great writers of antiquity were preserved and used during the times when wars were not being waged.

Even during these trying times some of the monks compiled animal stories which were, however, concerned principally with pointing out a moral. Such stories were collected in book form and became known as the **Physiologus.** The Physiologus in turn developed into another book of similar import called the **Bestiaries,** while on the botanical side a book, which may be compared with the Bestiaries, was the **Hortus Sanitatis.**

Later, another botanical work appeared, called the **Herbals.**

In the thirteenth century, Europe became somewhat settled. There was then sufficient leisure and safety to permit men to take up a studious life. The fame of the great scholars of that day spread rapidly. Everywhere studious men sought whatever books they could find, and read them. Printing had not yet been invented, so it was only in the monastery libraries that books (written by hand) could be found. These were read with avidity, and much which had lain neglected during the years of war and turmoil now was made known to the new generation. This period from about 1250 to 1500 is therefore called the **Renaissance** or **Re-birth Period.**

During the thirteenth century, the Dominican Monk **Albertus Magnus** (1193-1280), began working on physical experiments while the

Dominican **Thomas Aquinas** (1225-1274) began to collect and coordinate all the scientific and philosophical knowledge of his day.

Following these came the Franciscan Monk, **Roger Bacon** (1214-1294), the real father of modern science. Among his many writings we find the first clear and unmistakable statements from which our knowledge of modern lenses date. His work is like a modern monograph in that it gives recognition to the opinions of others.

The old Romans had, it is true, used pieces of glass with water in between for magnifying purposes, but it was Bacon who set men on the right path regarding true observation, description, and the use of modern laboratory instruments.

Gesner (1516-1565) wrote his **Historia Animalium** in several volumes between 1551 and 1587, which was widely read, although he had but little influence on successive generations.

The next truly great name in the history of biology is that of **Vesalius** (1514-1564). He wrote the **De Humani Corporis Fabrica** in 1543. Up to this time the surgeon would not soil his hands by touching and cutting the body. Such work was left for barbers, who performed their dissections and operations under the direction of the surgeon. Vesalius dissected with his own hands, and then described and pictured what he found. Vesalius' old master, **Jacobus Sylvius,** was a strenuous opponent of his pupil, as was also Vesalius' own pupil, **Columbus.** However, another pupil of Vesalius, who later became his successor at the University of Padua, was **Fallopius** (1523-1562), who built upon the work of his master.

Harvey (1578-1657) in 1628 published his **Excercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus** in which he showed conclusively that the blood flows in a circle from the heart throughout the blood-vessels and back again to the heart.

In about 1600 compound microscopes were invented, and it is from this time forward that the great microscopical discoveries were made which have changed our modern conception of many ancient problems.

Robert Hooke (1635-1703) wrote his **Micrographia** in 1665 in which he called attention to the "little boxes or cells" of which plants are composed. It is he, therefore, who gave us our first notion of the cell.

The next important name is that of **Van Leeuwenhoek** (1632-1723) who first saw Bacteria, Infusoria, Yeast, Rotifers, Hydra, and a host of other organisms which were totally unknown up to his time. His work, which attracted most attention in the scientific world, however, was his description of **spermatozoa.** His imagination ran away with him, for he was sure he saw definitely-formed tiny human beings in the spermatozoa. A great conflict was waged by those who agreed with him and those who opposed Van Leeuwenhoek and his school (the spermists), insisting that it was the sperm which was the all important factor in producing life, while his opponents (the ovists) insisted that it was the egg which developed into new offspring.

Swammerdam (1637-1680), in his **Biblia Naturae,** compiled long and painstaking researches on the anatomy of insects which, up to his time, were considered unorganized physical masses.

Malpighi (1628-1694) of Bologna worked on plants and animals. He made elaborate studies and illustrated them, on the development of the plant-embryo, as well as on the embryology of the chick, the anatomy of the silk-worm, and the structure of glands.

Chronologically, the **systematists** should be mentioned at this point, but logically, it is better to introduce the student to the whole subject of Classification and the men who did the classifying at the same time, so this subject will be given in the next chapter.

However, as soon as there is any considerable classification and description of a subject, men begin to divide that subject into individual parts or units, so that workers may narrow their field and confine their work to such limited group or unit.

Comparative Anatomy, Physiology, Histology, Embryology, Genetics, and **Organic Evolution,** are the main divisions into which Biology is thus divided.

The work done by first-year students of biology, as set forth in this book, consists of studying a **type-form** of the principal phyla of plants and animals, and then attempting to develop biological principles from the knowledge thus gained. This first-year work therefore includes the fundamentals of Botany and Zoölogy. The Third Semester's work is confined to the specialized study of **Embryology,** and the Fourth Semester's work is **Comparative Anatomy and Physiology.** In this last Semester's work the student studies in detail **each organ or organ-system** of the great divisions of Zoölogy and then compares these, system by system.

Probably the first man to attempt this latter method was **Severinus** (1580-1656) of Naples. In 1645 he published a volume suggesting that all vertebrates and man had much in common, structurally. However, over a century before this time **Belon** had made drawings of the skeletons of birds and man and placed them side by side so that differences and similarities could be noted. Then came **Tyson** (1650-1708) of Cambridge, who is the father of our modern method of treating comparative findings in monograph form. His work was a comparison of man and monkeys.

Cuvier (1769-1832) of Paris is, however, the first of the great men in this field of work. He was the first to embrace both living and extinct forms in his comparisons, and he also obtained a wider grasp of the problem confronting him than any of his predecessors. A good illustration of the synthesis sought for, and the breadth of knowledge desired in this department of research, can be found in his famous statement, "Give me a tooth, and I will construct the whole animal."

This is the key-note to **comparative study.** It means that every change in function modifies a structure, and that if we can know thoroughly all there can be known about function and its effect on structure, and every change in one structure which may change a related structure, we can, if we are given a structure, tell what the functions must have been, and **vice versa.**

There are men who were lesser lights in the field of Comparative Anatomy even before Cuvier's time, whose names it is well to know. **John Hunter** (1728-1793), who founded the Hunterian Collection in England; **Camper** (1722-1789) of Groningen, and **Vicq d'Azyr** (1748-1794) in Paris. All of these did synthetic work, but their breadth of knowledge, view, and vision fell far short of that of Cuvier.

Following Cuvier came **Milne-Edwards** and **Lacaze-Duthiers** in France; **Meckel, Rathke, Johannes Müller,** and **Gegenbaur** in Germany; **Owen** and **Huxley** in England; **Aggassiz, Cope,** and **Marsh** in America. When men once became interested in the great structural problems of Zoölogy it was but natural that others should become interested in those that were functional. Here was the birth of modern **physiology.** The medical men were the first to do work in these fields. They established systems of thought known as the **iatro-mechanical** and **iatro-chemical schools.**

Haller (1708-1777) took the work of these men, surveyed it and evaluated it, so that he may really be called the **father of modern physiology.**

The first work in this new field was done on nutrition and respiration. **Reaumur** (1683-1757) of Paris, and the Abbe **Spallanzani** (1729-1799) of Pavia, did the most remarkable work in this field, although they had forerunners on whose work they built in turn.

Such forerunners were **van Helmont** (1577-1644), **Sylvius** (1614-1672), **Bishop Stensen** (1638-1686), **de Graff** (1641-1673), **Peyer** (1653-1712), and **Brunner** (1653-1727).

The great names in chemistry whose work affected biological students are primarily **Boyle** (1627-1691), **Priestley** (1732-1804), **Lavoisier** (1743-1794).

In physiology proper the greatest names in Germany are: **Liebig** (1803-1873), **Wöhler** (1800-1882), the brothers **Weber** (E. H., 1795-1878, and W. E., 1804-1891), **Ludwig** (1816-1895), **Helmholtz** (1821-1894, **Johannes Müller** (1801-1858), and **du Bois-Reymond** (1818-1896). In France, **Dumas** (1800-1884), **Magendie** (1783-1889), and in England, **Hall** (1790-1857). The greatest of the physiologists is undoubtedly **Johannes Müller.**

In Botanical physiology, **Hale (1677-1761),** is the greatest, while

Cesalpino (1519-1603), **Jung** (1587-1657), and **van Helmont** (1577-1644), occupy high places.

Ingen-Housz (1730-1799) was the first to show that carbon dioxide from the air is broken down in the leaf when the plant receives sunlight, and that the carbon is retained which thus assists materially in nutrition and growth.

De Saussure (1740-1799) showed further that water and various salts from the soil produced the remaining factors in this process, while **Boussingault** (1802-1887) gave us our knowledge of chlorophyl.

Haller and **van Leeuwenhoek** were what is called **pre-formationists.** They supposed that each sperm or egg-cell already contained an embryo somewhat fully formed, and that all that occurred during the growth period was an enlarging of the parts which were already present. Such an idea meant that every human germ-cell must have every other complete human being that could ever descend from it, within itself, fully formed, but very small. We know now that both those who held this theory and those who opposed it were wrong. There must, of course, be a **potentiality** present in each germ-cell which can develop into what it is to become, but this by no means signifies that the embryo possesses a definitely formed embryo within it in turn. The new embryo is always organized little by little until it becomes the completed individual adult organism.

However, it is natural to see how and why observers thought they saw the complete embryo in the egg. In our study of Embryology we shall see that when the hen lays an egg, it is already from twenty-four to thirty-six hours old, and consequently, even when we have a freshly laid egg (provided it is fertile) there is already an embryo which can be seen. It was with material of this kind that these men had to work.

Wolff (1733-1794) had proved that the performationists were in error, but **Haller,** who held the intellectual reins of workers in zoölogy at the time, refused to accept it and so the lesser lights also refused.

It was but natural that after **Hooke** had observed that plants were composed of cells that something should be done with such a finding. **Brown** (1773-1858), working on the cell, discovered the **cell nucleus** in 1831, and the botanist **Schleiden** (1804-1881), and the zoölogist **Schwann** (1810-1882) published their works in 1838 and 1839, respectively, showing that plants are developed from cells and that plants and animals are alike in being composed of cells.

An important point was made in suggesting that each cell has two functions: one to perform the work of itself and the other to perform a task which makes it an integral part of a larger organism.

Schultze (1825-1874) in the early sixties established the idea of **protoplasm** as the living substance of all cells. This protoplasm was called by Huxley the **"physical basis of Life."**

In Embryology **Fabricius** (1537-1619) published a paper describing the sequences of development in the hen's egg up to the time of hatching. **Harvey** was a pupil of Fabricius, and built upon the work of his master. These men opposed the preformationists, and called their theory **epigenesis**—which simply means that the embryo arises by a gradual differentiation of unformed material in the egg.

Malpighi in 1672 sent two important papers on Embryology to the Royal Society, but apparently the time was not yet ripe for his work and it was neglected for nearly a century. He stood with the epigenetic group.

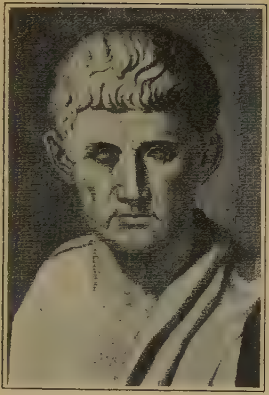
Bonnet (1720-1793) was one of the important men at this time who threw the weight of his influence with Haller toward the preformationists.

At present embryologists hold, as was stated above, that there really is an organization of some kind in both egg and sperm, but that no embryonic shape has yet been established. The definite shape comes forth only by the gradual differentiation of the unformed (but not unorganized) matter. We may therefore say "the whole future organism is potentially and materially implicit in the fertilized egg cell," which means that both sides were partially right.

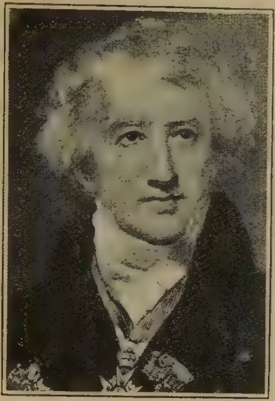
However, the greatest name in embryology is **von Baer** (1792-1876). His work was done in the thirties of the last century. He is the father of **comparative embryology.** It was he who first noted and described **cleavage, germ-layers, tissue and organ differentiation,** and gave us the well-known **"recapitulation theory,"** now often called **Haeckel's "Law of Biogenesis,"** on account of Haeckel's popularization of it. It will be remembered that this theory holds that embryos pass through the adult stages of the race to which they belong.

The origin of life has always been an interesting speculative subject for thinking men, and many and mysterious are the ways in which life was supposed to spring forth spontaneously. Aristotle thought that mice developed from the river's mud, while later writers suggested that old rags and cheese combined in a dark cellar would produce the same result. The history of this subject makes more than fascinating reading.

Francesco Redi (1626-1698) was probably the first man to demonstrate experimentally that life did not spring forth spontaneously as commonly supposed. He placed very thin cloth over a dish containing decaying meat and found that when flies were thus prevented from coming in contact with the meat, no maggots formed, although maggots were always supposed to arise spontaneously from decaying meat. But Redi himself found parasites of various kinds within the bodies of other animals, and these he could not account for, so his experiment, while a classic, did not settle the problem for others any more than it did for himself. The settling of this vexed question was left for **Louis Pasteur** (1822-1895), who first showed that decay was not the cause of microorganisms but the result of them. His experiments were made while



Aristotle, 384-322 B. C.



Cuvier, 1768-1832.

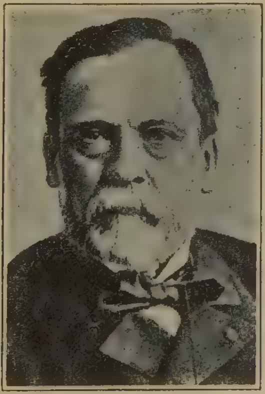
Francesco Redi, 1626-1697.

Lazzaro Spallanzani, 1729-1799.

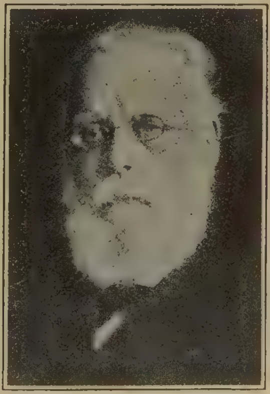
Johannes Müller, 1801-1858.

Robt. Brown, 1773-1858.

Max Schultze, 1825-1874.



Louis Pasteur, 1822-1895.



August Weismann, 1834-1914.

Fig. 243.

(Aristotle and Max Schultze, from Needham's "General Biology" by permission of The Comstock Publishing Co., Publishers. Pasteur, from G. Stuart Gager's "Fundamentals of Botany" by permission of P. Blakiston's Sons & Co., Publishers. Remaining photographs from Wm. A. Locy's "Biology and its Makers" by permission of Henry Holt & Co., Publishers.)

working on fermentation problems, and it is from his work that all modern medicine dates, for he was the founder of the science of Bacteriology.

In **Genetics** or **Inheritance,** from a purely biological angle, **August Weismann's** (1834-1914) work, **The Germ Plasm,** stands out prominently. It was Weismann who called our attention to the fact that the bodily characteristics of any individual have but little, if any, effect on succeeding generations. He held that **germ-plasm** alone carries inheritance. In other words, that acquired characteristics are not likely to be inherited, and that if we are to make any change in future generations, we must first learn how to make a change in the germ-cells.

Francis Galton (1822-1911) gathered a great quantity of statistics on the stature of parents and children and published the result of his research in the eighties.

The most important name in the study of inheritance is that of the Augustinian Monk, **Johann Gregor Mendel** (1822-1884), who combined experimental breeding of plants with a thoroughly scientific philosophy and evolved from this combination the **Mendelian laws** which are now used wherever breeding experiments are performed, whether on plants or animals.

In the field of **Organic Evolution,** one may find among the ancients many thoughts which show conclusively that they were not unaware of a gradual change from smaller beginnings to greater and more developed products. And **St. Augustine** (died 604) also calls attention to the fact that a God is the greater, the more potentialities he can enclose within a smaller area, which potentialities can then unfold and evolve.

Among the moderns, **Buffon** (1707-1778), was the first to obtain a clear inkling of geographical isolation, struggle for existence, and artificial and natural selection, and he propounded a theory of how variations came about through environment.

Erasmus Darwin (1731-1802) wrote on changes going on in the animal world and embodied his ideas in verse.

Lamarck (1744-1829) is the most philosophical, which means the most profound, of all the writers of the evolutionary school, as he actually tried to explain WHY changes took place in the organic world.

Cuvier (1769-1832), who was a contemporary of Lamarck, and who at that time held the highest attainable place in the zoölogical world, was a consistent opponent of Lamarck, but **Geoffroy Saint-Hilaire** (1772-1844), though never attaining the rank of Lamarck, was a staunch upholder of the Lamarckian principles, and **Goethe** (1749-1832), the famous poet, who was also a famous scientist of his day, became a disciple of the new doctrine.

Lyell (1797-1875), the Englishman, in the early thirties of the last century wrote his **Principles of Geology** which convinced men that the same causes now in action always had been, and that we could therefore, by studying the time it took to make present changes in the earth's surface, estimate the length of time and the age of the various strata of the earth.

With the intellectual soil prepared in this way **Charles Darwin** (1809-1882), published his epoch-making book, **The Origin of Species by Natural Selection,** in 1859. Darwin accepted, without explaining, the fact that variations do occur. He assumed that the origin of existing species could be explained by accepting the fact that variations did occur, and that nature then selected which organisms should continue to exist by killing off those which did not inherit as many variations of a survival value. He assumed that acquired characteristics were inheritable, and that the struggle for existence eliminated the unfit. Darwin had spent twenty years in gathering the facts on which he based his theory, but **Alfred Russel Wallace** (1822-1913) had reasoned out a similar theory without having the facts that Darwin had, and it is an interesting coincidence that both men were working on the same thought at the same time, though independently. Darwin was willing to surrender all his work to the younger man, but Wallace insisted that Darwin was to have the credit as the latter had done such an immense amount of work on the matter.

Evolution now serves the biological world as a sort of general plan of the results of heredity, while **genetics deals with the factors which produce these results.**

Thomas Huxley (1825-1895), though not a believer in the Darwinian theory of Natural Selection, sprang to the defense of Darwin, primarily, as Professor Poulton says, because Darwin was so constantly and persistently treated unjustly. And it was Huxley who made Darwinism popular. **Hooker** (1817-1911) in England, **Haeckel** (1834-1919) and **Weismann** in Germany, and the Botanist **Gray** (1810-1888) in America, were early converts. Haeckel, however, was too much of the showman, and was always willing to sacrifice truth and accuracy to win his point.

Summing up what has been said, we may say that **the basis of greatness in science is not the brilliancy of an individual discovery, but the finding and enunciating of a principle which can find many applications by those who follow.**

The great findings, considered from this point of view of obtaining **principles** and wide influence in biology, may be said to be **the discovery of protoplasm; the establishment of the cell-theory; the theory of organic evolution; the demonstration that germs are a tremendous factor in disease;** and the experimental study of inheritance as suggested by the work of Mendel and Weismann.

And the most important writings of the most important men may be summarized here by following Professor Wm. Locy's account, which we have modified slightly.

THE MOST NOTABLE MEN AND WRITINGS IN BIOLOGY

The progress of biology has been owing to the efforts of men of very human qualities, yet each with some special distinguishing feature of eminence. Certain of their publications are the mile-stones of the way. It may be worth while, therefore, in a brief recapitulation to name the books of widest general influence in the progress of biology. Only those publications will be mentioned that have formed the starting point of some new movement, or have laid the foundation of some new theory.

Beginning with the revival of learning, the books of **Vesalius, "De Corpora Humani Fabrica"** (1543), and **Harvey, "De motu Cordis et Sanguinis"** (1628), laid the foundations of scientific method in biology.

The pioneer researches of **Malpighi** on the minute anatomy of plants and animals, and on the development of the chick, best represent the progress of investigation between Harvey and Linnaeus. The three contributions referred to are those on the "Anatomy of Plants" **(Anatome Plantarum)**, (1675-1679); on the "Anatomy of the Silkworm" **(De Bombyce**, 1669); and on the "Development of the Chick" **(De Formatione Pulli in Ovo** and **De Ovo Incubato**, both in 1672).

We then pass to the **"Systema Naturae"** (twelve editions, 1735-1768) of Linnaeus, a work that had such wide influence in stimulating activity in systematic botany and zoölogy.

Wolff's "Theoria Generationis," 1759, and his **"De Formatione Intestinorum,"** 1764, especially the latter, were pieces of observation marking the highest level of investigation of development prior to that of Pander and von Baer.

Cuvier, in **"Le Regne Animal,"** 1816, applied the principles of comparative anatomy to the entire animal kingdom.

The publication in 1800 of **Bichat's "Traite des Membranes"** created a new department of anatomy called histology.

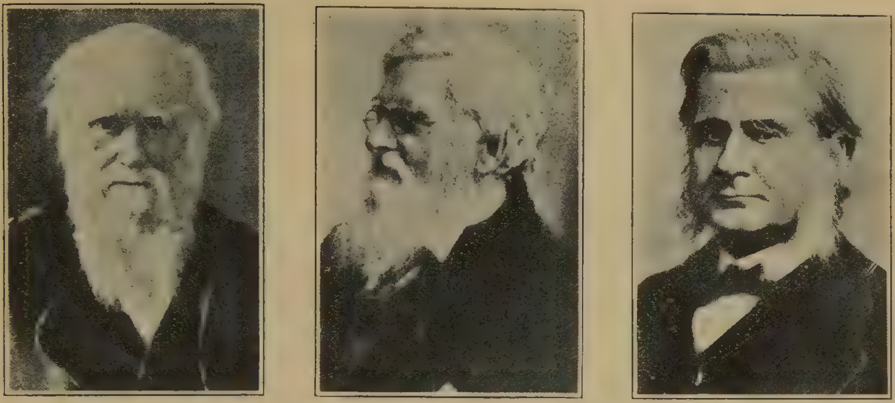
Lamarck's book, **"La Philosophie Zoölogique,"** 1809, must have a place among the great works of biology. Its influence was delayed for more than fifty years after its publication.

The monumental work of **von Baer** "On Development" **(Ueber Entwicklungsgeschichte der Thiere)**, 1828, is an almost ideal combination of observation and conclusion in embryology.

The **"Mikroscopische Untersuchungen,"** 1839, of **Schwann** marks the foundation of the cell-theory.

The "Handbook" of **Johannes Müller (Handbuch der Physiologie des Menschen)**, 1846, remains unsurpassed as to its plan and its execution.

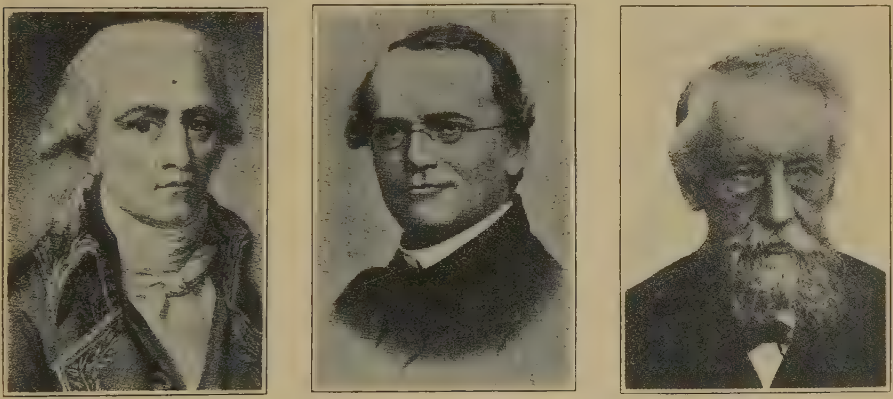
Max Schultze in his treatise, **"Ueber Muskelkoerperchen und das was man eine Zelle zu nennen habe,"** 1861, established one of the most important conceptions with which biology has been enriched, viz: the protoplasm doctrine.



Charles Darwin, 1809-1882

Alfred Russel Wallace, 1823-1913

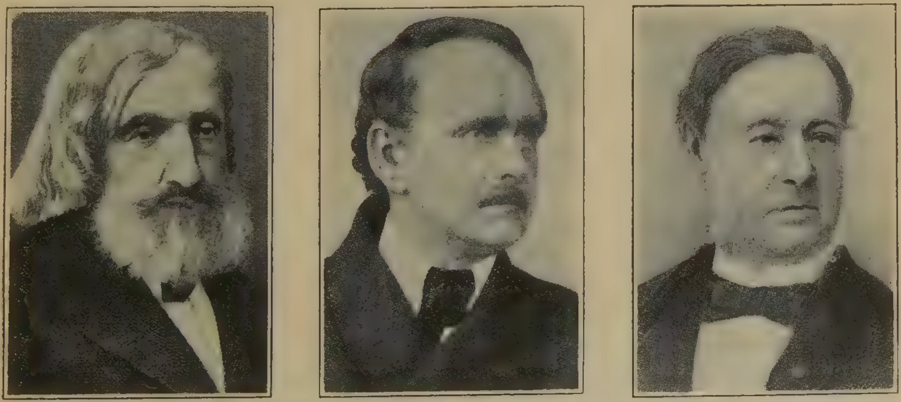
Thomas Henry Huxley, 1825-1895



Lamarck, 1744-1829.

Johann Gregor Mendel,

Hugo DeVries. 1848—



Karl Ernst von Baer, 1792-1876.

M. Schleiden, 1804-1881.

Theodor Schwann, 1810-1882.

Fig. 244.

(De Vries and Mendel, from G. Stuart Gager's "Fundamentals of Botany" by permission of P. Blakiston's Son & Co., Publishers. Remaining photographs from Wm. A. Locy's "Biology and its Makers" by permission of Henry Holt & Co., Publishers.)

Darwin's "Origin of Species," 1859, is, from our present outlook, the greatest classic in biology.

Pasteur's "Studies on Fermentation," 1876, is typical of the quality of his work, though his later investigations on inoculations for the prevention of hydrophobia and other maladies are of greater importance to mankind.

Mendel's "Versuche über Pflanzen-Hybriden" appeared in 1865 in a little Journal in Brünn, Austria, where Mendel was Abbot of the Augustinian Monastery. It remained entirely unknown to the scientific world until 1900 when three workers in the natural sciences rediscovered it. These men were De Vries, Torrens, and Tschermak.

Mendel's work has become the foundation upon which all modern research along genetic lines is based. Castle says, "Mendel had an analytical mind of the first order which enabled him to plan and carry through successfully the most original and instructive series of studies in heredity ever executed," and Bateson suggests that "had Mendel's work come into the hands of Darwin, it is not too much to say that the history of development of evolutionary philosophy would have been very different from that which we have witnessed."

Weismann's "The Germ-Plasm, A Theory of Heredity," appeared in 1893. It demonstrated the "continuity of the germ-plasm," a valuable starting point for theorizing upon Mendel's Laws.

De Vries' "Die Mutationstheorie," published in 1901, caused much of Darwin's theory, that evolution comes about gradually, to be set aside. The sudden springing forth of new forms, rather than a slow change requiring thousands of years, won many scientific men to it. In fact, all modern evolutionary theories follow either the Darwinian or the De Vriesian type, or build new ones on modifications of these.

It is somewhat puzzling to select a man to represent the study of fossil life. One is tempted to name E. D. Cope (1840-1897), whose researches were conceived on the highest plane. **Zittel** (1839-1904), however, covered the entire field of fossil life, and his **"Handbook of Paleontology"** (1876-1893) is designated as a mile-post in the development of that science.

Before the Christian era, the works of **Aristotle** and **Galen** should be included.

From the viewpoint suggested, the most notable figures in the development of biology are: **Aristotle, Galen, Vesalius, Harvey, Malpighi, Linnaeus, Wolff, Cuvier, Bichat, Lamarck, von Baer, J. Müller, Schwann, Schultze, Darwin, Pasteur, Zittel, and Mendel.**

Such a list is, as a matter of course, arbitrary, and can serve no useful purpose except that of bringing together into a single group the names of the most illustrious founders of biological science. The individuals mentioned are not all of the same relative rank, and the list should be extended rather than contracted. Schwann, when the entire output of the two is considered, would rank lower as a scientific man than Koelliker, who is not mentioned, but the former must stand in the list on account of his connection with the cell-theory. Virchow, the presumptive founder of pathology, is omitted, as are also investigators like Koch, whose line of activity has been chiefly medical.

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Albert H. Buck, "The Growth of Medicine from the Earliest Times to about 1800."

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A. G. Little, "Roger Bacon. Essays contributed by various writers on the occasion of the commemoration of the seventh century of his birth." (1914.)

CHRONOLOGICAL TABLE OF IMPORTANT BIOLOGICAL EVENTS

B. C.

540 Xenophanes: first to recognize fossils as proving that the earth was formed under the sea and rose out of it.

500 Heraclitus: often called the first evolutionist; he first advanced the principle that "all things flow."

450 Empedocles: first to suggest natural selection and survival of the fittest.

400 Hippocrates: called "the Father of Medicine."

350 **Aristotle**: founder of zoölogy.

320 Theophrastus: first botanist.

320 Erasistratus: first to give mechanical explanation of disease symptoms.

300 Herophilus: first anatomist.

A. D.

79 Pliny: wrote first popular natural history.

160 **Galen**: founded medical physiology.

1266 Bacon: wrote his Opus Majus.

1542 **Vesalius**: founder of modern anatomy.

1548 Falloppio: anatomist.

1551 Gesner: gathered first botanical garden (of fruits and flowers) and first zoölogical museum.

1560 Eustachio: anatomist.

1583 Caesalpinus: classified plants by flowers.

1590 Janssen, J. and Z.: discovered compound microscope.

1603 Fabricius: discovered valves in the veins.

1603 **Harvey**: discovered circulation of the blood.

1622 Ascello: discovered the lacteals.

1649 Rudbeck: discovered the lymphatics.

1650 Swammerdam: first great student of insects in relation to plants and medicine.

1661 **Malpighi**: founder of pathology; discovered the capillaries in the lungs; founded modern embryology by a study of the incubation of the chick (1672).

1667 Leeuwenhoek: first to see bacteria.

1668 **Redi**: disproved spontaneous generation of insects by the discovery of eggs and larvae; wrote "Esperienze intorno alla Generazione degl' Insetti."

1670 Mayow: studied animal respiration.

1671 Hooke: worked out microscopical structure of plants.

1680 Borelli: proved that all the movements of animals are caused by muscles pulling on bone levers; wrote "De Motu Animalium."

1682 Grew: studied structure of plants.

1693 Ray: classified plants.

1727 Hales: investigated respiration of plants.

1743 **Haller**: father of modern physiology.

1744 Reaumur: studied insects.

1749 **Buffon**: wrote a natural history.

1753 **Linnaeus**: founder of modern botany; classified plants.

1761 Koelreuter: studied hybridization of plants.

1764 Bonnet: evolutionist; grouped animals in an ascending series.

1764 Wolff, Friedrich, Caspar: overcame the **preformation** doctrine.

1772 Rutherford: discovered nitrogen.

1774 Priestley: discovered oxygen and studied the breathing of plants.

1775 **Spallanzani**: disproved spontaneous generation of bacteria and molds and demonstrated presence of living germs in the air.

1789 Galvani: discovered animal electricity.

1790 Goethe: worked out a scheme for the metamorphosis of the parts of plants.

1794 Darwin, Erasmus: grandfather of Charles Darwin; wrote "Zoonomia," a long poem outlining evolution of life.

1796 Jenner: discovered vaccination.

1796 Sprengel: studied fertilization of plants.

1800 **Cuvier**: founder of modern comparative anatomy; wrote "Le Regne animal," 1817.

1800 **Bichat**: founder of modern histology.

1801 **Lamarck**: invented a scheme for the evolution of animals (by conscious effort and inheritance of acquired characters; not proved).

1801 Treviranus: introduced the name "biology" as distinguished from "botany," "zoölogy," "physiology," "anatomy," etc.

1804 Humboldt: studied distribution of plants.

1807 Rumford, Count: demonstrated absorption of carbonic acid by plants.

1811 Bell, Charles: discovered motor and sensory nerve roots; founder of modern neurology.

1818 G. St. Hilaire: pointed out unity of plan in animals.

1823 Von Baer: discovered the law of embryological development; (all higher forms pass through somewhat similar forms to lower ones in the embryological period).

1830 Brown: described cell nucleus.

1833 **Müller, Johannes**: founder of modern comparative physiology. Wrote **Handbuch der Physiologie des Menschen.**

1835 Dujardin: studied protoplasm.

1838 **Schleiden**: discovered the cell as unit of structure in plants.

1838 **Schwann**: discovered the cell as unit of structure in animals.

1839 Agassiz: wrote on fresh-water fishes.

1841 Helmholtz: discovered rate of nerve impulse.

1853 Mohl: studied protoplasm (living substance).

1857 **Pasteur**: founder of bacteriology; studied fermentation.

1858 **Darwin**: reported his work upon the origin of species by natural selection and applied evolution to man.

1858 Wallace: reported his work upon the origin of species by natural selection.

1858 **Virchow**: worked out cellular pathology; founder of modern cellular pathology.

1861 **Schultze, Max**: established protoplasm doctrine.

1863 **Huxley**: wrote "Evidence as to Man's Place in Nature."

1863 Lyell: wrote "The Antiquity of Man."

1865 Sachs: studied structural botany.

1865 **Mendel**: founder of modern genetics; discovered the law of heredity.

1867 Lister: worked out aseptic surgery.

1875 **Galton**: studied inheritance.

1875 Hertwig, O.: studied fertilization.

1880 Koch: proved the relation of bacteria to disease.

1880 Laveran: discovered malarial parasite (in the mosquito).

1886 Leuckart: settled the modern classification of animals; specialized on parasites.

1893 **Weismann**: showed that germ-plasm and somatoplasm are distinct.

1893 Zittel: wrote most important work on fossils.

1888 Finlay } discovered relation
1898 Reed } between yellow fever
1898 Lazear } and the mosquito.
1898 Howard: discovered relation between typhoid fever and the house fly.
1900 **De Vries,** Correns, Tschermak: all working independently, rediscovered Mendel's law of heredity.
1903 Stiles: discovered hookworm in the United States.
1914 Goddard: proved feeble-mindedness a unit character.
1915 Stockard: discovered influence of alcohol on offspring.

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CHAPTER XXVI.

PALEONTOLOGY

Just as we attempt to read and interpret the history of man's progress in the handicrafts, and in the remnants of tools and pottery which are found in various parts of the world, so we attempt to read and interpret the changing conditions which have taken place in the earth's crust by the study of geological and paleontological findings. Geology concerns itself with the changes in the earth itself, while paleontology seeks to build up a meaningful account of the changes which may have taken place in living organisms throughout the past, as demonstrated by their fossil remains (Fig. 245).

There are two general ways in which layers of rock and soil have been laid down. The first has come about by great masses of molten substance forming within the earth which were then thrown out by volcanic action. Such masses harden to form minerals and other heat products. If the minerals then become concentrated, they are called ores. All such products formed by heat are known as **igneous formations.**

The second way in which changes have come about is this: Various horizontal soil-layers have been shifted about by climatic changes such as a subsiding of land surfaces and an elevation of the edges of the ocean. This causes the lowered continent to be covered by shallow water, and later, when this condition is again reversed, a layer of sediment is left behind. It is in this sediment that millions of marine-forms of life are stranded. If now, the sediment hardens, and these marine organisms are safely protected from air and superficial decay, their bodies will be preserved as fossil remains.

Fossil remains are, therefore, observed most frequently in the deposits on the floors of lakes, in peat-marshes, in the deltas of river-mouths, and under the stalagmites in caverns in lime-stone districts.

The exceptional conditions necessary to preserve organic forms will rarely be found everywhere, so that we must remember that no matter how many fossil remains may be found, only a very infinitesimal portion of the living forms of any given period will become known to us. Then, too, in those which are preserved most, if not all, of the softer parts of the organism are destroyed, only the hard portions remaining.

The necessity for coördinating the facts found in many and varying ways is of prime importance in the science of Paleontology, for without such coördination there is neither sense nor value in its study. This will be demonstrated quite clearly in what follows.

Geology and climatology attempt to explain each other, the former by its effect upon climate, and the latter by its effect on the changing strata which go to make up the earth's surface. In fact, it is the changing climatic conditions which give us the terms "ages" or "periods," such as the **carboniferous age** and the **glacial period.**

<table>
<tr><th>PSYCHOZOIC</th><th>19,000 to 150,000 YEARS</th><th colspan="2">RECENT</th><th></th></tr>
<tr><td rowspan="4">CENOZOIC
or
(Tertiary)
5% of Geologic Time
5 Miles Deep</td><td>Age of Man, Insects and all those Mammals now living All Phyla of Plants including highest flowering Plants.</td><td colspan="2">Quarternary or Pleistocene (pleistos = most + Kainos = recent) Glacial Period Also called Metal age or Palaeolithic ages</td><td>Tapir, Pecary, Bison, Llama, Equus, Megatherium, Mylodon.
(Gigantic sloths) (Gigantic sloths)</td></tr>
<tr><td>All trace of Man lost
Mammals abundant, many of which are now extinct
Pithecanthropus (Pithekos = ape + anthropos = Man) Found in Java Probably at close of Pliocene Period</td><td rowspan="3">TERTIARY
(Age of Mammals)
2,900,000 years</td><td>PLIOCENE
(pleion = more
Kainus = recent</td><td>Equus Beds (Equus = Horse)
Equus, Tapirus, Elephas
Pliohippus Beds Hippus = Horse
Pliohippus, Mastoden, Bos., etc</td></tr>
<tr><td>Primates Had made great Progress, Ancestral Stock of gibbons
Dryopithecus (Drus = Tree + Pithekus = Ape)
Large Anthropoids
Increase in higher flowering Plants</td><td>MIOCENE
(meion = less
Kainus = recent)
(Not found in Engl</td><td>Miohippus Beds
Miohippus, Diceratherium (2 horned), Thinohyus.
Oreodon Beds. (Orae = Mou ∧ in + odont = Tooth)
Edendates. Hyoenodon, Hyrocoden.
Brontotherium Beds. (Bronte = Thunder + Therion = Beast)
Mesohippus, Menodus, Elotherium</td></tr>
<tr><td>Mammalian Forms abundant Many now extinct
Increase in flowering Plants</td><td>EOCENE
(eos = dawn
Kainus = recent)</td><td>Diplacodon Beds Epihippus. Amynodon.
Dinocerus Beds. Tinoceras, Uintatherium
(Deinus = terrible + Keras = Horn)
Limnonyus, Orohippus, Helaletes, Colonoceras.
Coryphodon Beds. Eohippus, Monkeys,
(Coruphe = Summit + odont = Tooth
Carnivores, Ungulates, Tillodonts, Rodents.</td></tr>
<tr><td rowspan="5">MESOZOIC
or
(Secondary)
12% of Geologic Time
11.5 Miles Deep</td><td rowspan="3">Birdlike Reptiles
Flying Reptiles
Toothed Birds
First Snakes.
Bony Fishes abound; Sharks numerous;
Rapid increase of Lower Flowering Plants</td><td colspan="2" rowspan="3">CRETACEOUS
(Chalky)
(Age of Reptiles)
5,000,000 years</td><td>Lignite Series
Hydrasaurus, Dryptosaurus</td></tr>
<tr><td>Pteranodon Beds. (Pterodactus = winged reptile + anodon = Toothless)
Birds with Teeth, Hesperornis.
Ichthyornis, Mosasaurs
Pterodacthyls, Plesiosaurs.</td></tr>
<tr><td>Dakota Group</td></tr>
<tr><td>First Birds,
Giant Reptiles,
Ammonites,
Clams and Snails abundant
Ferns, Cycads, and Conifers.</td><td colspan="2">JURASSIC
(Limestone as in the Yura Mts.
2,000,000 years</td><td>Atlantasaurus Beds
Dinosaurs, Apatosaurus.
Nanosaurus, Turtles, Diplosaurus.</td></tr>
<tr><td>First Mammal Found.
(a Marsupial);
Sharks reduced to new Forms,
Bony Fishes appear
Ferns, cycads, and Conifers.</td><td colspan="2">TRIASSIC
(Three layers = Sandstein, Muschelkalk and Keuper)
2,000,000 years</td><td>Connecticut River Beds.
Dinosaur Foot-prints, (Amphisaurus)
Crocodiles, (Belodon).</td></tr>
</table>

Fig. 245.

Composite Palaeontological Chart, compiled from many authors, showing geological strata and fossil-forms found in each. It will be noted that the number of years assigned each stratum varies from any given amount to ten and even a hundred times that number. The student must therefore realize that all such estimates are only guesses. What he must know is the relative percentage of time and the relative percentage of depth of each layer and speak only in terms of "eras" and depths.

Professor Osborn has just described (*Natural History*, for November-December, 1921) a Tertiary man living long before the ice-age.

If the deposition of the earth's layers have been laid down by water and air, the various strata show such causes by forming a coarse sand-layer, followed by a layer of finer sand or mud; or, two sandy layers will be found separated by thin layers of muddy shale, the exact formation depending upon the velocity of both sand and water.

Or, there may be mechanical and chemical changes which produce beds of rock-sand or gypsum between beds of marl. Likewise organic activities may have their influence as shown by the fine beds of coal succeeding layers of sand, or by a layer of large fossils imbedded in limestone.

PALÆOZOIC (Primary) 19% of geologic time 18.5 Miles Deep	Earliest of true Reptiles, Amphibians; Lung Fishes; Fringe Fins; First Cray Fishes, Insects abundant; Spiders; Fresh Water Mussels. Ferns; Calamites. Lycopods, Cycads, Conifers.	CARBONIFEROUS (Age of Amphibians) 3,000,000 Years		Permian Red Sandstone, etc Magnesian Limestone
				Coal Measures. First Reptiles(?)
				Subcarboniferous Carboniferous Limestone
	First Amphibians. (Froglike Animals) Sharks; Ostracophores. First Long Shells (Snails) Mollusks abundant First Crabs Ferns Calamites Lycopods Cycads Conifers	DEVONIAN (Age of Fishes)		Corniferous Schoharic Grit
	First truly terrestrial or air-breathing animals; First Insects; Corals abundant, Mailed Fishes Probably some Land Vegetation	SILURIAN	Upper Silurian	Sandstones, Shales, Some Limestone
	First Known Fishes; Ostracophores; (Fishes having no jaws, Segmented Backbones or Limbarches & Forepart protected by bony Plates; Cartilaginous Skeleton; Brachiopods, Tribolites; Mollusks, etc.		Ordovician or Lower Silurian	Slates, Sandstones, Volcanic Rocks, etc.
	Invertebrates only. Probably some Higher Algae	Cambrian	Primordial	Slates Sandstones, etc
ARCHÆN 64% of geologic time 62 Miles Deep	Simple Marine Invertebrates Probably very simple Algae	ARCHÆN	Huronian	Slates, Volcanic Rocks, etc No Vertebrates Known
			Laurentian	

Fig. 245.

As there is a tremendous pressure of the superincumbent layers upon the underlying strata, the lower layers as well as their fossil contents are often crushed and injured. Extreme care must, therefore, be taken to interpret one's findings. One can readily grasp what such pressure would accomplish in the delicate layers of shale (called paper-shales) which range from sheets as thin as paper to layers of such sheets fifty feet or more in thickness.

A study of the fossil remains of plants and animals should show us in what order these organisms lived and followed each other in times long past, and it is usually conceded that they do; but, it is not an uncommon thing to find an earlier fossil layer lying above a later one. Geologists explain this by saying that changes have again taken place which reversed these lower beds, or thrust earlier strata between other layers. All this complicated arrangement lends itself to deceptive interpretation. For example, those who oppose the usually accepted geological evidence of "periods of time" and "successive ages" say that the arrangement of the various strata is so deceptive that it can only be explained by a world-upheaval of some kind, and that, therefore, no evidence of successive ages is worth anything.*

An interesting example of the order in which certain strata have been formed, is found in instances where trees and their stumps are found lying in a more or less semi-upright position. Often the stump-part and roots still lie in their position of growth or at least they lie in a deeper stratum than the upper and less heavy portion. Such trees were either pushed over by streams of water or carried along by the stream. The heavier end became caught or weighted, and sank, while the upper end remained in a position of slant in the direction of the current. It is, of course, also possible that the trees were entirely submerged while still growing, but in the latter case the rate of sand-deposit must have been sufficiently rapid to lay down an accumulation of at least forty feet (enough to cover the erect tree) before the wood decayed.

Former regions have been identified by the occurrence of great quantities of drift-wood found in the strata, as having been quite close to land, while differences in climate are evidenced by the finding of tropic plant and animal remains in cold regions, and arctic plants and animals in tropic regions.

Migrations of plants and animals from one region to another are demonstrated by their fossil remains being found in different types of strata in different ages.

However, no one can tell the number of years required to lay down the various strata any more than he can tell how many years elapsed to form the intervals between such laying down; and these intervals no doubt were often much longer than the time it took to form the strata.

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*G. McC. Price, "The Fundamentals of Geology."

Intense cold or heat, resulting from a climatic change, undoubtedly killed many organisms which were unable to adapt themselves to the changing conditions of the past, while mountain ranges becoming elevated cut off the moisture-supply of others who went the same way.

The glacial period is considered synonymous with the **permian,** and represents the extreme of cold, while the **tropical period,** the extreme of heat, is represented by **coal beds** (Fig. 245).

The mechanics of adaptation of living organisms to new climatic and environmental changes has given rise to much speculation.

Lamarck thought that the organism was directly affected by any change in environment and that this change then affected the germplasm so that it could be inherited by the organism's offspring, and thus result in a permanent racial change.

Others taught that both somatoplasm and germplasm are simultaneously affected. This theory is known as that of **parallel induction.**

Darwin, like Lamarck, believed that small environmental changes became large ones as they were successively inherited. In fact, this was held by nearly all the early workers since the time of Darwin; but, as no evidence was forthcoming which could explain how such environmental changes could affect the germplasm and thus be inherited, biologists are inclined to hold with Professor H. H. Newman, that "external factors accelerate or retard processes that were already under way in the germplasm, so that the response appears to be something new in kind when it is only the result of a sudden acceleration of a character evolution already under way. Whatever be the underlying mechanism involved in adaptive changes, there is no hope of explaining adaptations on the Darwinian basis, through the selection of the best out of a vast area of purely fortuitous variations; for if the historical study of vertebrate evolution reveals one thing more clearly than any other, it is that evolutionary changes are ordinarily progressive, and determinate in character, and that in many respects these ordinary processes of evolution are independent of each other and of environmental changes."

This means that we need not hold that animals always adapt themselves to their environment, but that they can migrate to environments which are best suited to them. And there is ample evidence to show that such migrations took place quite often. Some of these are shown by the land-bridges (over which animals passed) now destroyed, which connected islands and continents with each other. The animals were then shut off from their original home by the destruction of the bridges. Such animals are said to be **geographically isolated.**

Not only have animals migrated, but as already stated, the climate itself migrated. This is shown by the fact that the marine and glacial coverings of the land's surface took place at much later periods in some places than in others.

To return to the fossils themselves, it is necessary for the student to understand the various forms in which fossil remains come down to us. Bones may be buried in silt which then hardens. Later, water, containing minerals, may make its way through the silt and bit by bit dissolve the bone, and deposit a mineral in its place. This is **petrification.** The shape and form of the bone remain intact, though the original bone-substance is replaced by a mineral.

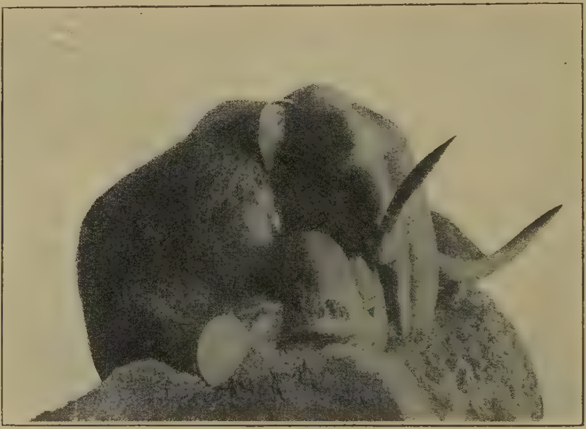

Fig. 246.

Mammoth found frozen in Siberia. The skin is mounted in the museum of Petrograd in the posture in which it was found. (From Lull's 'Organic Evolution,' by permission of the Macmillan Co., Publishers.)

Or, an organism may retain its form long enough to have the surrounding substance completely encase it and harden. As time goes by the organism is dissolved and disappears, while the hollow space it occupied remains. Such hollow forms, in the shape of organisms no longer present, are called **molds.** Investigators fill these molds with a material such as plaster of paris (which hardens easily) and obtain a **cast** of the original organism.

Then, too, as stated above, the tremendous pressure of the upper layers may crush the fossil forms beneath, or the minerals which caused petrification may be re-dissolved, so as to expose the fossil remains to conditions which destroy them, and this may happen after they have been so encased for thousands of years. Weathering and erosion may also expose fossils to the harmful effects of the weather.

When very definite fossil remains are always found in certain strata, they are often called "index fossils," as such fossils can be used to determine the place and period of the strata from which they are taken.

One of the most interesting finds in 1901 was that of an ancient animal, whose species is now extinct, that of a mammoth found frozen in the ice of Siberia (Fig. 246), whose flesh was in excellent condition.

In oil-bearing sands many excellent fossil specimens have also been well preserved.

But the fossil remains which have excited most discussion and speculation are those which are supposed to have belonged to human beings higher in the grade of life than the highest apes we now know, and yet

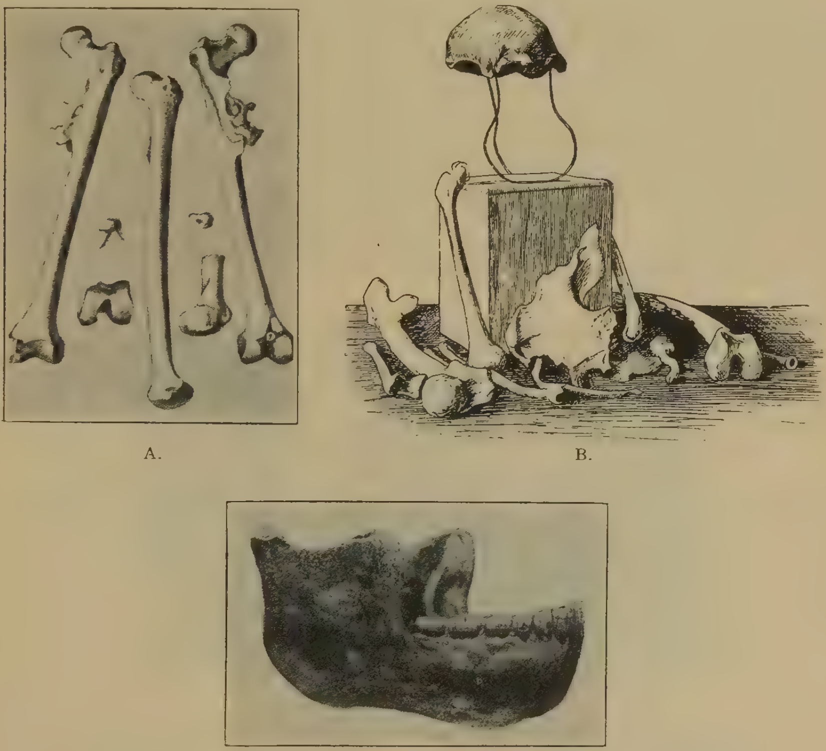

Fig. 247.

A. Remains of *Pithecanthropus erectus;* the single femur shown in different aspects.
B. Remains of the Neanderthal man in the Provincial Museum at Bonn.
C. The Heidelberg Jaw.
(A. From "The Open Court", B. from "Weltall V. Menschheit", C. from Bryce after Schoet Ensack.)

distinctly lower than man. Authorities, however, disagree considerably as to what type of being these bones represented, some insisting their possessor was human, and some that he was not.

One of the most important of these "finds" (1891-1892) is that of a part of a skull, two teeth, and a femur (Fig. 247, A). These parts lay at some distance from each other, so that we cannot be certain that they belonged to the same individual, but it is assumed they do. The shape of the femur indicates that its owner walked in an erect position and was about as tall as men now are. From the parts thus found a so-called "reconstruction" was made to show what the reconstructor thought the individual must have looked like. The name **Pithecanthropus erectus** is applied to the individual who once possessed these bones (Fig. 248). The bones are presumably from the early **Pleistocene period.**

At another time a lower jaw with its teeth was found near Heidelberg in Germany (Fig. 247, C). As the teeth are not ape-like, but approach those of man, the individual who possessed them has been called **Homo-heidelbergensis.** The fossil remains of various animals found in the same region with the Heidelberg jaw give us the age of this find as that of the **second interglacial** period, which means that this jaw is only about one-half the age of **Pithecanthropus erectus.**

In 1856 there was found in Prussia the skeleton of what is called the Neanderthal man (Fig. 247 B, and 248), or **Homo-neanderthalensis** which comes from about the fourth glacial period, so that it is about one-third the age of the Heidelberg man.

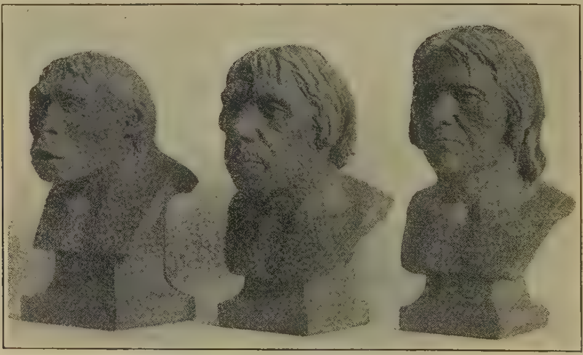

Fig. 248.

Restoration of prehistoric men. Left, *Pithecanthropus erectus;* middle, *Homo neanderthalensis,* modeled on the Chapelle-aux-Saints skull; right, Cro-Magnon man, modeled on type skull of the race. (From the original busts of, and by courtesy of, Professor J. H. McGregor.)

Then in France and Wales a number of skeletons have been discovered in which the skull is narrow and the face broad, something like that of the Esquimaux. The cheek bones and chin are also prominent. Professor J. H. McGregor has molded busts in accordance with his idea of what such men must have looked like (Fig. 248).

There is no connection whatever between these various forms so we cannot in any way prove they are a genetically continuous series. All conclusions built upon these finds must, therefore, be purely conjectural.

From the evidence presented here, we note the fact that many present-day forms of both plants and animals are unlike their ancestors. We are, therefore, confronted with four possible explanations of why they are different: (1) that present-day forms are the lineal descendants of ancestral forms unlike themselves and that all new forms with ever increasing complexity spring from older ones; (2) new forms different from the older ones have been created at different periods; (3) all forms were brought into existence at about the same time, but due to a great world upheaval the fossiliferous strata have been so confusedly arranged that while all fossils are of one age, it is our mistaken interpretation which makes us believe they are of different ages; or (4) organisms came into existence which at the time of their origin had the possibility of change placed within their germ-plasm, but which had to await the proper conditions of food and environment before they could come forth to produce present-day forms.

If it be accepted that any present-day forms are different from their ancestors, and that these new forms can produce offspring capable of transmitting that change to their posterity in turn, we must speak of an **evolution** as having taken place.

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CHAPTER XXVII.

EVOLUTION

The student must not forget when discussing evolution that this term means only that some present-day forms have become unlike their ancestors, and that such difference is then transmittable—in other words, **that it has affected the germ-plasm.**

Evolution as it applies to the individual is therefore the name given a **process** by, and through, which an organism evolves or changes into a different type of being from its parents.

In the chapter on Genetics, we have seen how all offspring vary to a small extent, not only from their parents, but from each other. When such differences are slight they are called **variations** and the organisms possessing them are known as **varieties.** When such variations become sufficient to set aside the new organism as a quite different type from its parents, the new types are known as different **species.**

It will be noted that this is quite vague; for, what one man may consider a difference sufficient to form a new species, another may not. There is, therefore, no good definition of the term **species.** Biologists disagree to a very marked extent as to what it means.

Members of the higher groups of animals are often considered as belonging to the same species if they can inter-breed and give birth to fertile offspring in turn. But, if we are to accept this definition, there never can be any strictly new species; for, if animals can inter-breed, their offspring will belong to the species to which their parents belong, and if they cannot, there will be no offspring.

Then, there are those who take the position that only those individuals form true species which **always breed true.** If we accept this definition, it may be said that whenever a so-called new-form or **mutation** (as it is called) comes forth, such new-form is in reality only the return of some ancestral type, which has been formed by the meeting of an egg and a sperm, both of which carried recessive characteristics. From this angle one may always explain new species as being old ones, again coming forth.

However, species generally mean **groups of individuals who possess similar outstanding characteristics, which characteristics can be transmitted to their offspring.**

First, then, in discussing evolution, one must be convinced that new species really do come into existence, otherwise there can be no evolution. Practically all biologists now hold that new species do come into being, which means that they accept evolution as a **fact.** There is, however, a vast difference of opinion as to the limitations within which evolution operates, both in the individual and in the race, as well as to the method by which evolutionary changes come to be what they are.

Secondly, if all present-day forms have sprung from ancestors unlike themselves, the question arises as to whether all the different phyla sprang from one original living being (whether evolution is **monophyletic** or **monogenetic**), or whether there were numerous "first forms" from which all successive forms spring (**polyphyletic** or **polygenetic** evolution).

Having settled for ourselves as to whether evolution is a fact, we set about trying to find a theory which will account for that fact.

There have been only two great theories advanced. One by Charles Darwin, known as **Darwinism** or **Natural Selection**, and the other by Korschinsky, and De Vries, known as the **Saltation** or **Mutation** theory, or **heterogenesis.**

Darwinism holds that, as we have seen, the offspring of a single pair of flies will be almost six billion in ninety days if all eggs were to hatch, it follows that were such increase to continue in all animals and plants, the food-supply would soon become exhausted. There must, therefore, be a **struggle for existence** to determine which plants and animals are **fittest to survive.**

Everyone has noted that millions of eggs, maggots, and insects never reach the adult form of life on account of their being eaten by various animals. The number of flies and other insects are, therefore, dependent upon the number and activity of their natural enemies as well as their own physical ability to avoid such enemies, together with their ability to obtain a sufficient supply of food and water for themselves.

It follows that there will be a **struggle** even among the same group of organisms for food and water, while the whole group must struggle against their many natural enemies. Nature, through such struggle, selects the strongest and most active (as these are the only ones which will not succumb to the struggle) to carry on the race. The particular characteristics which make it possible for plants and animals to survive in this struggle for existence, are said to have a **survival value.**

Darwin accepted **variations in all living organisms** as a fact, and built his theory on that fact. He contended that useful variations by possessing a **survival value** were transmitted to the offspring of such organisms, so that each succeeding generation received the advantage of its parents' **acquired characteristics.**

However, it is generally held now that acquired characteristics are practically never inherited, and that natural selection only explains why certain organisms did not die and others did. It cannot explain **the origin** of new species.

Darwinism is based on the assumption that there are very **minute changes** constantly taking place in the organism. These changes have an effect on the germ-plasm of the individual, thus altering it, causing the change to be transmitted. For example, a giraffe by constantly eating food from trees, finds it necessary to reach higher and higher. This stretching of the neck will, then, in each generation cause the young giraffes to be born with a slightly longer neck.

If such a change makes the individual better able to **adapt** itself to its surroundings and thus gives it an advantage in the struggle for existence, it is said to be a **selective factor.**

The **mutation theory,** contrary to the Darwinian, insists on sudden jumps or great changes taking place which are then transmitted. This theory is based on the fact that there are so-called "freaks" or "sports" in nature which suddenly spring forth.

The crooked-legged sheep is the classic example. A New England ewe gave birth to a peculiar crooked-legged ram. The shrewd Yankee farmer, who owned the sheep, saw in this crooked-legged ram an animal that could not jump fences, and so kept it. The **crooked-leggedness** proved to be a **Mendelian dominant character** which is transmitted from parent to offspring. There are now great numbers of the descendants of this single New England crooked-legged ram, which are in turn crooked-legged.

Such mutations can be explained by assuming that the recessive characters in egg and sperm have met after lying dormant for many centuries.

In fact, there are a number of examples of characters lying dormant and being carried on from parent to offspring, only coming forth at certain times when the mating organism likewise has a similar dormant or recessive character. For instance, many mullein plants will, in certain years, suddenly produce longer leaves than is normal for that plant, thus showing that the cause of the longer leaves must be in the germ plasm of the varying plants. For if such were not the case, there would not be so many to develop longer leaves in the same generation.

In other words, this means that there is a peculiar arrangement of genes in the chromosomes of the mating-plants, and these genes have united to cause a similar abnormal development in all those plants which spring from similar zygotes.

It is for reasons of this kind that biologists have come to the conclusion that environment does not change the organism to any appreciable extent in its genetic value, but, that whenever changes come forth, these are due to changes in the germ plasm.

To the two great theories mentioned above, there have been added at various times what might be called sub-theories or part-theories to account for certain developmental characteristics. The most prominent of these is known as **Orthogenesis.** **Eimer** and **Nägeli** are its sponsors. Orthogenesis means that there is something in the organism which, once a line of development has begun, this something will enable the organism to continue in that certain line of development even though it kill the individual. An example which comes to mind is the teeth of rodents. These, when the animal becomes older and is unable to chew the hard substances it did when young, continue to grow with the same undiminished vigor that they did when they were constantly being worn down by contact with hard substances, so that they may, as in the beaver, force the mouth open and starve the animal to death.

But Orthogenesis must be explained, and various reasons have been suggested to account for it, the reasons varying according to the "philosophy of life" of the one who is doing the explaining.

Those who hold that all things are to be explained in terms of physics and chemistry, attempt to explain orthogenesis in physico-chemical terms, while those who hold that there is an inner driving force in all living matter which cannot be explained by physics and chemistry, insist that it is this inner driving force, or "vitalistic principle," which alone can account for it.

Both sides, however, agree that the cause for this development is not in the organism's environment, but must be sought for in the organism itself. As Professor Borradaile puts it, "The part of the environment is to decide which of the experiments of the organism are failures." And there is sufficient evidence to accept his statement. For instance, the fertilized egg-cells of nearly all the higher organisms are quite alike, yet they develop quite differently. And they retain this difference in development, even if the egg is transplanted into the body of a different kind of animal and is there allowed to develop to maturity. There must be a difference in the environment of the organs within the bodies of different animals, yet the egg grows on as it would have done under its normal environment.

When such definite direction takes place it is called **purposiveness.**

The objection raised against the physico-mechanists (those who believe that all things can be explained in terms of physics and chemistry) by those who do not hold to their point of view (vitalists) is that the body cannot be accepted as a machine in any true sense of the word. A machine produces a very definite and single type of work, while the living organism has all its work directed toward its own welfare, and unlike any machine known, can, when it is injured, direct its entire working system toward repairing itself in addition to continuing its regular work. It not only heals the wound inflicted, but actually grows new material, as we have seen by the regeneration experiments in **Planaria** and **Arthropoda.**

Then, too, there is a decided chasm dividing living and non-living matter; so much so, that it is a common dictum of biology that absolutely no life can come from non-living matter, there being no single case on record of any organism coming into existence except as the offspring from some other organism.

However, as we know living things did not exist always, there must have been a time when they did come into existence. The physico-mechanists say, that while no living matter comes from non-living today, yet, as there must have been a time when it did, we must assume that different conditions once held sway from those we now know.

But, such being the case, we break the most important law known to science—that of **continuity.** It is for this reason that it has been said, that the breaking of this law of continuity is the only heresy known to evolutionary science.

The theory that life always comes from life is known as **biogenesis,** while the theory which holds that life can come from non-living matter is called **abiogenesis.**

It will be noted that the evolutionary theories so far discussed have only taken the **physical side** of the individual into consideration to the entire neglect of the mental and intellectual.

It was **Alfred Russel Wallace,** co-founder of the Natural Selection theory with Darwin, who saw this quite early, and insisted that the psychical or mental side must also be considered if we are to form truly valid conclusions. He contended that once mentality enters, as it does in man, such an organism could use this mentality to set aside or change the physical selection which Nature carried on. In other words, the earlier evolutionists were interested in the **structure** of nerves and nerve elements, while Wallace saw the necessity of taking the **thought** which is carried by the higher nerve centers into consideration.

It is well for the student to know both the evidence adduced in support of evolution and evolutionary theories, and the objections which have been hurled against it. We have, therefore, summed up the arguments of both sides, whether such support and objections are always conclusive or not.

EVIDENCES FOR EVOLUTION

1. Paleontological.

(a) There are many new kinds of plants and animals found in each successive strata as shown by their fossil remains.

(b) The later organisms are more complex than earlier ones.

(c) The more recent fossils prove that they are quite closely related to the modern forms now living.

2. Genetics.

Breeding experiments as well as observation prove that all organisms are constantly varying, and that constant variations in the same group of organisms are transmitted to succeeding generations.

3. Comparative Anatomy.

The similarity of structure in different individuals is precisely what would be experienced if evolution did take place.

Homology (similarity of structural development) is to be regarded as a sign of relationship, as it is assumed that in such cases little or no structural change has taken place in times past. Contrariwise, organisms which are quite dissimilar in structure are assumed to have diverged many ages ago.

4. Comparative Embryology.

(a) Likenesses between embryos of different animals are assumed to demonstrate a close fundamental relationship and a common ancestor. An example often quoted is that of **Sacculina** (Fig. 212), a parasite on the abdomen of the crayfish. This parasite is merely a rounded, pulpy mass with no clearly defined structure except a little root-like projection, which extends into the body of the host to absorb the fluids. The embryo of **Sacculina,** however, is a very definitely shaped three-cornered little organism with jointed legs and all other necessary features which bring it under the crustacean classification. In fact, it is practically a degenerated barnacle.

(b) All higher forms of vertebrates possess so-called **gill-pouches** during the embryonic stage, although the higher forms do not retain them in the adult stage. This would lead to the assumption that the common ancestors of vertebrates must have been fish-like.

(c) According to von Baer and Haeckel, all animals during the embryonic period pass through the adult forms of the race to which they belong, thus presenting conclusive evidence of the history of their descent.

5. Comparative Physiology.

Animals which are closely related genetically have a somewhat similar blood-composition, as proved by the fact that the blood of one such related animal can be successfully transfused to another without harm.

6. Geographical Distribution.

Animals such as marsupials (pouched animals) which have as much in common structurally as the Australian kangaroo and the American opossum, while yet quite unlike in general appearance, can only be accounted for by taking the geological evidence for a land-bridge into consideration which once connected Australia and America. The two animals having had the same ancestry, changed their appearance because of a changed geographical environment, although their general structure has remained quite as it was.

There are no native ungulates in Australia, although there is no reason why there should not be if other than evolutionary methods have been factors in producing new types of animals.

Or, again, one finds, for example, on the west coast of South America, peculiar animals found nowhere else in the world, while on the neighboring islands there are animals resembling those on the coast of the continent both in structure and habit, yet sufficiently different to be called new species.

7. **Natural Selection.**

This is an attempted explanation of why present-day forms are what they are, by showing that food is never equal to the possible rate of increase in living forms. Such lack of food causes a struggle for existence through which struggle the weakest (the ones being least adaptive), go down, while the stronger (those best able to adapt themselves to their environment), survive.

Natural selection describes the causes which have prevented surviving forms from becoming extinct.

OPPOSING ARGUMENTS

The arguments which are usually brought forth to oppose these evidences for evolution are as follows:

1. **Paleontology.**

(a) The different kinds of plants and animals found in various geological strata can only demonstrate that similar organisms were either larger or smaller than others, or varied in ways which can be accounted for by a difference in the temperature and food supply of different ages. Examples of this are the horse and mammoth. Then, too, paleontologists insist that their finds can only be explained by assuming that acquired characteristics are inherited, although experimental evidence seems to point against this being true.

(b) The so-called increasing complexity on the part of so-called "younger" fossils as compared with so-called "older" ones, may always be explained by assuming that Mendelian recessive characteristics have again come forth, and that consequently the so-called "new forms" are really a return of old ones.

(c) Recent fossils are like modern forms because the climatic changes and the food supply have not varied much during the interval between our own time and the time when the prototypes of these recent fossils lived, and that examples of so-called older forms (those which lie above the recent forms) can be considered evidence for this statement.

(d) Those who insist on experimental evidence which is always under the control of the experimenter, say that fossil-remains furnish us only with "descriptions" of what is found. It is a "dead" account. It can never give us an explanation. Explanation and interpretation can only come through our logic. Paleontological evidence is therefore all logical and not experimental. A strictly scientific explanation from the experimentalist's point of view must also present experimental evidence. This has not been, and cannot be, done in paleontology.

2. Genetics.

(a) Inherited changes can always be referred back to ancient Mendelian recessives meeting, and thus producing a "past" type. There can be no strictly "new" types ever formed because the chromosomes never die (as long as there are living offspring), and all that ever happens is that some part of them is thrown out. But, from what is known of biology, it is impossible to add anything to the offspring which is not already present in the chromosome content of the germ cells.

(b) Mendelian characters themselves are only concerned with minor details such as eye-color, hair-color, and similar matters. No change of a definite survival value has yet been shown to come under its laws.

3. Comparative Anatomy.

Similarity of structure by no means proves relationship, as shown by examples of **convergent evolution**, where two quite dissimilar structures come to look alike in various aspects, due to similar functioning. Witness such experiments as Carey's in which bladder-muscle was converted into beating heart-muscle by causing the bladder to simulate heart-conditions.

The argument from comparative anatomy holds good only if one accept the dictum that "structure determines function," while the experiment just mentioned shows that function determines structure, once one has the material with which to work.

4. Comparative Embryology.

(a) Any organ not used is likely to degenerate. This accounts for **Sacculina** degenerating when it assumed a parasitic habit where it no longer uses the various organs it once used. This is not remarkable, and if it proves anything, it proves only that an organism can lose something it once possessed, though it by no means proves that what we have been considering a more complex organism, can arise from one that is less complex.

(b) The so-called gill-pouches demonstrate only as in (c) that vertebrate forms pass through similar stages of growth and not that one springs from the other.

(c) If the Haeckelian law is to hold good, that embryos pass through the adult stages of the race to which they belong, we are confronted with some unacceptable conclusions. For instance, only the human being walks in an entirely upright position. In man alone there are three complete bends in the developing brain which remain throughout adult life. It is assumed that only his upright position can account for the third bend, which brings the cerebral hemispheres back over the brain-stem. But in the chick, and in practically, if not all, vertebrates, these three bends take place in the embryo. It is later that at least one, and sometimes two, of the bends disappear. We must therefore assume that frogs, chicks, lizards, etc., once walked erect like man, an assumption that not even the most ardent defenders of the Haeckelian law will admit.

5. Comparative Physiology.

Similarity of blood-composition in quite similar forms is to be explained again on the principle that all similar forms go through a similar development, and that with similar food and temperature, the blood must necessarily have to be quite similar because it must draw its component substance from the same food material.

6. Geographical Distribution.

This, like Natural Selection, can only show why some organisms survived. It throws no light on origins. It can show how parts of an organism may be lost, but not how additional complexity has come.

7. Natural Selection.

This explains nothing of importance. It fails utterly to explain the degeneration of useless organs, and why variations of great magnitude do not occur more often, as well as why and how a simultaneous variation in different parts of the body takes place to improve a definite organ.

8. Psychology.

All the evidence evolutionists adduce to prove their arguments is invalid because they take only the physical side of the organism into consideration, forgetting the most important part—the mental.

9. Logic.

We have been reversing the order of things, by forgetting that if a tiny cell or organism has the ability or potentiality of becoming a highly complex animal, it must be much more complex than the later organism into which it is to grow. For, surely the smaller an object may be, which can contain all that it is later to become, the greater in complexity it must be. And, if such a tiny object is so intensely complex, it could not have suddenly sprung into existence without an intelligence of some kind arranging it.

10. Physics.

The student of depth has been driven into out and out skepticism of anything being true in science, or has gone over entirely to mysticism, because he cannot overcome the obstacle which the acceptance of the laws of the different laboratory sciences place in the way of his biological findings. For example, Physics tells him that no more work can be obtained from a machine than is put into it, and that nothing can rise higher than its source. Then the evolutionist tells him (in contradiction to these laws) that more complex forms come from those less complex. This belies both laws, for Intelligence is certainly something higher, and more than non-living matter. And intelligence cannot be explained in terms of either physics or chemistry.

If it be told the student that the energy of the sun furnishes the energy which can do all these things, and that there is a law known as the conservation of energy, he will read the statement of various eminent physicists who tell him that the sun's heat will gradually become less and less, finally becoming entirely dispersed. Consequently there will not be as much as there once was, and the law is broken. This brings him back to the place from which he started. "How did the energy and the potentiality of a simple organism become complex, and how did the developing intelligence become what it is, unless it got it from something still greater?"

11. Language and Intelligence.

If it be proved that plants and animals have arisen in an ever-ascending plane, how account for language and intelligence (true ability at thinking which is then expressed in words)? Can this **psuchus** or **psychon,** or real intellectual part of man, have come from anything less than a still greater intelligence?

12. Continuity.

As was shown in the chapter on the "History of Biology," the very foundation of science, as now understood, is based on the law of continuity, namely, that the laws of nature never vary. Yet we find all biologists agreeing that the law of continuity has been broken, by the fact that living forms must have once sprung from non-living, a condition now no longer true. This is the great "heresy" of evolutionary science. As life and mentality do not now operate as they once did, when, where and how did they begin?

13. No Satisfactory Theory of Evolution.

No theory of evolution yet propounded is satisfactory because none has satisfied the requirements set forth above.

14. Impossibility of a Satisfactory Physical Explanation.

There exist certain rays known as infra-red, and ultra-violet, which no human eye can see; yet, these rays can be proved to exist by the physicist. If the ultra-violet rays are thrown upon a group of brown ants they will immediately scatter quite hurriedly, thus demonstrating their ability to sense rays which man cannot.

Now, it is probably from such evidence as this that one biologist, at least, draws the conclusion that just as there are undoubtedly thousands of colors which no human eye can see, and thousands of sounds no human ear can hear, so there must be thousands of factors in every explanation which the human mind cannot grasp. This being true, it follows that if we can find any explanation which is plausible, and which fits in with every nook and crevice of our mind, we know that such a theory is not likely to be true, because there are thousands of points that we must necessarily have neglected taking into consideration due to our sheer intellectual inability. Thus even the most plausible arguments are vitiated.

SUMMARY

We have presented practically all of the important arguments for and against evolution itself and the various theories which attempt to account for it, because it is just as essential for a well-educated man to know the opposing arguments in any given case as it is for him to know the supporting ones. The theories which the student is to accept are those which he finds sufficient evidence for in his work throughout his laboratory course.

Regardless of what one may believe the evidence has brought forth, all biological workers must accept evolution as a scientific hypothesis, though this does not mean that they must accept any of the theories propounded to account for it. The above statement is true, because there is much more evidence to show that an evolution has taken place than there is to show how and why it took place.

Then, too, the student must note the difference between the **cause of evolution** (which the various evolutionary theories try to explain) and the **course of evolution.** This latter is only a description of what has been found, as, for instance, the charts which show the various fossil-remains of what is considered the ancestors of the horse and mammoth. Such charts, of course, **explain** nothing.

The Darwinians originally held to the doctrine that all variations must possess some function of a survival value, but we now know that characters which are a decided hindrance in the survival sense, are inherited and passed on from one generation to another just as readily as those which are of value.

Two different types of organisms may often grow to be quite alike, or at least certain organs may develop so as to appear alike if they function alike. This growing alike is known as **convergent evolution.** Individuals originally structurally alike, which later become dissimilar, are said to do so through **divergent evolution.**

From what has been said above, one is likely to agree with the writer who said that every biologist seems to have his own pet theory to account for the evolutionary process.

Notwithstanding this fact, one must, however, have some kind of a gauge by which to measure the plausibility of a proposed theory. Otherwise there is not even an approach toward finding whether any given evidence is of value.

It is to assist the student in forming such a gauge that the following seven questions are here tabulated. These must be answered by any theory which is to win complete and final acceptance.

CRITERIA FOR A SATISFACTORY EVOLUTIONARY THEORY

These questions refer to organic evolution in its widest signification, as referring to both the individual and the race.

(1) How did life originate?

(2) How can a more complex individual develop from ancestors which were less complex?

(3) How can an organism adapt itself to its surroundings?

(4) What causes the so-called mechanically directed types of variations known as Orthogenesis?

(5) What causes the series of the many undoubtedly purposive adaptations?

(6) What causes the factors of heredity to behave as they do?

(7) What factors can account for mentality and intelligence (which are non-physical things) arising from physical and non-mental matter?

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CHAPTER XXVIII.

CLASSIFICATION

It has already been shown that one may classify living things as to structure or function, that is, as to **anatomy** or **physiology.** The early naturalists felt that the most important thing in the study of living matter consisted in finding names and assigning definite places for every distinct individual. A little later morphology, or anatomy, was considered most important. Still later physiology, or the way an animal performs vital activities, was the all important thing. Then with the discovery that urea, an organic compound, could be manufactured in the laboratory, much stress was laid upon chemistry. It was formerly quite common for naturalists to look for **differences,** in order to classify the individual, while now we look primarily for **similarities** in order to understand the close relationships which bind individuals into a common group.

Fig. 249.
Carl von Linne, 1707-1778.
From G. Stuart Gager's "Fundamentals of Botany" by permission of P. Blakiston's Son & Co., Publishers.

Classification is now no longer the prime factor in the study of biology and men who are interested only in assigning names and groupings are not considered scientists. It must not be forgotten, however, that there could be no science possible, and biologists would be unable to discuss their work intelligently with each other unless some method could be found by which each would know what the other was talking about.

It is therefore well to know several of the important naturalists whose names are most intimately associated with this particular phase of Biology.

John Ray (1627-1705), an Englishman, was the first real systematist.

Following him came **Carolus Linnaeus** (Carl von Linne, 1707-1778), who is in reality the founder of our present method of classifying. In fact, one of the distinguished honors that may come to a Botanist is to be elected a Fellow of the Linnean Society. Linne's important work was his **Systema Naturae**, consisting of twelve volumes, which appeared between the years 1735 and 1768. There was a thirteenth volume added after his death. Linnaeus practically completed Ray's classification. He used **structure as the basis** of classification. There were six **classes,** four of which were vertebrate and two invertebrate. These classes were in turn divided into **orders,** the orders into **genera,** and the genera into **species.** However, the Linnaean Genus sometimes includes three or four orders of our present arrangement of groups.

Following Linnaeus came **Georges Cuvier** (1769-1832), who in turn was followed by **De Blainville** (1777-1850). The latter's method is considered superior to that of Cuvier.

Lamarck (1744-1829) classified animals **according to their nervous sensibilities,** speaking of **apathetic** animals, that is, those without nervous systems or apparent sensations among the invertebrates and the **sensitive** animals, largely also among the invertebrates, while the **intelligent** animals corresponded to the vertebrates.

Then came **Oken** (1779-1851), who suggested two different methods of classifying; neither one received much recognition. One of his systems was based upon the **arrangement of organs,** while the other was based upon the **senses.** The latter were divided into such interesting but valueless groups as **Dermatozoa** (literally, skin or touch animals), by which he meant the invertebrates; the **Glossozoa** (literally, tongue animals), the fishes; the **Rhinozoa** (nose animals), which included the reptiles; the **Otozoa** (ear animals) or the birds; and another class, which appears to have been called interchangeably the **Ophthalmozoa** (eye animals) or **Trichozoa** (hair animals), the mammals. It would be hard to name a set of distinctions less applicable as classification marks than most of these.

Pierre Latreille (1762-1833), **Johannes Müller (1801-1858),** and **Louis Agassiz** (1807-1873), should also be mentioned among the systematists.

The **Linnaean system** has been adopted because it introduced a sharply defined grouping and a definite terminology. In other words, this system permits a grouping of forms which **resemble** each other, as well as a grouping according to **relationships other than physical resemblance.**

As already stated, Linnaeus used four general groupings: **class, order, genus** (plural, **genera),** and **species.** Modern systematists have added **phylum** (plural, **phyla), subphylum** (assemblies greater than the class), **subclass, suborder, family, subfamily, genus, subgenus, species, subspecies,** and sometimes others.

The following table will illustrate the present method of naming and classifying animals:

Phylum. Protozoa
  Class. Rhizopoda
    ORDER. Lobosa
      Family. Amoebidae
        Genus. Amoeba
          Species. Proteus

The Botanists use a somewhat different classification, but the one here given is the one of greatest value and importance to the student.

All Zoölogists, although accepting this classification, do not necessarily classify the same animals under the same heading. This often leads to considerable confusion for the beginner.

The student of medicine will find that during the past twenty years a definite nomenclature has been adopted in the study of human anatomy known as the B. N. A., so called because it was brought about at an International Anatomical Conference at Basle, Switzerland, and therefore called the **Basle Nomenclatura Anatomica.**

The Linnaean system designates the species by **two Latin or Latinized names**; the **generic name** a noun, and the **specific name** usually **an adjective.** To this is added a third, if a subspecies is recognized. A **subspecies** is **usually** more or less **synonymous with variety in** classification, although variety is sometimes used; in fact, in one group, ants (family Formicidae), there are usually four words in the name.

The rules applying to the nomenclature, although following Linnaeus are set forth in various codes. These are the **British Association Code,** the **American Ornithological Union Code,** the **Code of the German Zoölogical Society,** and the **Code of the International Zoölogical Congress.** "The code now almost universally in use is the **International Code of Zoölogical Nomenclature,** adopted by the International Zoölogical Congress and governed through a Commission on Nomenclature." The principal rules are as follows:

"The first name proposed for a genus or species prevails on the condition that it was published and accompanied by an adequate description, definition or indication, and that the author has applied the principles of **binomial nomenclature.** This is the so-called **law of priority.** The tenth edition of the **Systema Naturae** of Linnaeus is the basis of the nomenclature. The author of a genus or species is the person who first publishes the name in connection with a definition, indication, or description, and his name in full or abbreviated is given with the name; thus, **Bascanion anthonyi** Stejneger. In citations the generic name of an animal is written with a capital letter, the specific and subspecific name without initial capital letter. The name of the author follows the specific name (or subspecific name if there is one) without intervening punctuation. If a species is transferred to a genus other than the one under which it was first described, or if the name of a genus is changed, the author's name is included in parentheses. For example, **Bascanion anthonyi** Stejneger should now be written **Coluber anthonyi** (Stejneger), the generic name of this snake having been changed. One species constitutes the **type** of the genus; that is, it is formally designated as typical of the genus. One genus constitutes the type of the subfamily (when a subfamily exists), and one genus forms the type of the family. The type is indicated by the describer, or if not indicated by him is fixed by another author. The name of a subfamily is formed by adding the ending **inae,** and the name of a family by adding **idae** to the root of the name of the type genus. For example, Colubrinae and Colubridae are the subfamily and family of snakes of which Coluber is the type genus."

Since evolution has become more or less of a keynote in the study of Biology, it has been the desire of Biologists to group living structures according to a **common ancestry.** This idea has been in the minds of systematists since Darwin's time.

Similarity of species of a given genus is supposed to **indicate kinship,** so that the individuals among any given genus show greater diversity than do the members of the species going to make up that genus, although all members of the genus have something in common. We may take as an example the **vertebrates,** which constitute the so-called **highest phylum,** and the **protozoa**—the single-celled animals—which constitute the so-called **lowest phylum.** Frogs being vertebrates, that is, having a backbone, are classified in the same phylum as man, who also has a backbone, but there is much greater difference between a frog and a man than there is between the many different species of frogs.

As already stated, Systematists have usually used structure for their important clue to affinities. "However, the **evidential value of similarity** in one or several structures **unaccompanied by the similarity of all parts is to be distrusted,** since animals widely separated and dissimilar in most characters may have certain other features in common. Thus, the coots ( ), phalaropes ( ), and grebes ( ), among birds have **lobate feet,** but, as indicated by other features, they are not closely related; and there are certain lizards (Amphisbaenidae), ( ), which closely resemble certain snakes (Typhlopidae), ( ), in being blind, limbless, and having a short tail. The early systematists were very liable to bring together in their classification **analogous** forms, that is, those which are functionally similar; or animals which are only superficially similar. In contrast with the early practice, the aim of **taxonomists** at the present time is to group forms according to **homology,** which is considered an indication of actual relationship. Since a genetic classification must take into consideration the entire animal, the search for affinities becomes an attempt to evaluate the results of all morphological knowledge, and it is also becoming evident that other things besides structure may throw light upon relationships. The **fossil records, geographical distribution, ecology,** and **experimental breeding** may all assist in establishing affinities."

It is, of course, necessary that before any final classification can be made one must know the various forms that exist and have existed in the past, and one of the greatest obstacles in this field is that most animals having a soft body have decayed and left no record of themselves among the fossil remains thus far found. Only those which possessed an intensely hard substance, or lived and died in regions where, due to the peculiar character of the soil or water, they were preserved, can furnish us with any accurate record of the past.

There are men who have taken up individual studies in order to ascertain all the details of their given specialties, and such men are named after the study-group they have adopted as such specialty; for example, one who specializes on the **protozoa** is called a **Protozoölogist**; one who studies **worms** is known as a **Helminthologist**; one who studies **mollusks**, a **Conchologist**; one who studies insects, an **Entomologist**, while he who studies **birds** is an **Ornithologist**, and he who studies **mammals**, a **Mammologist**.

It is, of course, understood that these men may not be interested in classification alone, but that they may be Anatomists, Physiologists, Ecologists, etc., also in regard to their favorite study.

The checking up of the different conclusions which different workers in the same field, and different workers in different fields have arrived at, is one of the most interesting and valuable studies possible. This is particularly true, because so frequently all the evidence that a Paleontologist accepts, points to a totally different conclusion from that which the student of experimental genetics finds to be true. The history of science is replete with cases of groups of men having held and defended doctrines most valiantly, and with seeming correctness, entirely opposite to those of men in other fields of study.

References.

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TABULAR VIEW OF THE CLASSIFICATION OF ANIMALS AS FAR AS ORDERS

(After Hegner, Schull, Handlirsch, Brues, Melander, Muttkowski, and Wheeler.)

PHYLUM I. PROTOZOA

Class I. Rhizopoda ( )
  Order 1. Lobosa ( )
  Order 2. Heliozoa ( )
  Order 3. Radiolaria ( )
  Order 4. Foraminifera ( )

Class II. Mastigophora ( )
  Order 1. Flagellata ( )
  Order 2. Choanaflagellata ( )

Order 3. Dinoflagellata ( )
Order 4. Cystoflagellata ( )

Class III. Sporozoa ( )
Subclass I. Telosporidia ( )
Order 1. Gregarinida ( )
Order 2. Coccidiidea ( )
Order 3. Haemosporidia ( )
Subclass II. Neosporidia ( )
Order 1. Myxosporidia ( )
Order 2. Sarcosporidia ( )

Class IV. Infusoria ( )
Subclass I. Ciliata ( )
Order 1. Holotricha ( )
Order 2. Heterotricha ( )
Order 3. Hypotricha ( )
Order 4. Peritricha ( )
Subclass II. Suctoria ( )

PHYLUM II. PORIFERA

Class I. Calcarea ( )
Order 1. Homocoela ( )
Order 2. Heterocoela ( )

Class II. Hexactinellida ( )

Class III. Demospongiae ( )
Order 1. Tetraxonida ( )
Order 2. Monaxonida ( )
Order 3. Keratosa ( )

PHYLUM III. COELENTERATA

Class I. Hydrozoa ( )
Order 1. Anthomedusae ( )
Order 2. Leptomedusae ( )
Order 3. Trachymedusae)
Order 4. Narcomedusae ( )
Order 5. Hydrocorallinae ( )
Order 6. Siphonophora ( )

Class II. Scyphozoa ( )
Order 1. Stauromedusae ( )
Order 2. Peromedusae ( )
Order 3. Cubomedusae ( )
Order 4. Discomedusae ( )

Class III. Anthozoa ( )
Subclass I. Alcyonaria ( )
Order 1. Stolonifera ( )
Order 2. Alcyonacea ( )
Order 3. Gorgonacea ( )
Order 4. Pennatulacea ( )

Subclass II. Zoantharia ( )
Order 1. Edwardsiidea ( )
Order 2. Actiniaria ( )
Order 3. Madreporaria ( )
Order 4. Zoanthidea ( )
Order 5. Antipathidea ( )
Order 6. Cerianthidea ( )

PHYLUM IV. CTENOPHORA

PHYLUM V. PLATYHELMINTHES

Class I. Turbellaria ( )
Order 1. Rhabdocoelida ( )
Order 2. Tricladida ( )
Order 3. Polycladida ( )

Class II. Trematoda ( )
Order 1. Monogenea ( )
Order 2. Digenea)

Class III. Cestoda ( )

PHYLUM VI. NEMATHELMINTHES

PHYLUM VII. ECHINODERMATA

Class I. Asteroidea ( )
Class II. Ophiuroidea ( )
Class III. Echinoidea ( )
Class IV. Holothuroidea ( )
Class V. Crinoidea ( )

PHYLUM VIII. ANNELIDA

Class I. Archiannelida ( )

Class II. Chaetopoda ( )
Subclass I. Polychaeta ( )
Order 1. Phanerocephala ( )
Order 2. Cryptocephala ( )

Subclass II. Oligochaeta ( )
Order 1. Microdrili ( )
Order 2. Macrodrili ( )
Class III. Hirudinea ( )
Class IV. Onycophora ( )

PHYLUM IX. MOLLUSCA

Class I. Amphineura ( )
Order 1. Polyplacophora ( )
Order 2. Aplacophora ( )

Class II. Gastropoda ( )
Subclass I. Streptoneura ( )
Order 1. Aspidobranchia ( )
Order 2. Pectinibranchia ( )
Subclass II. Euthyneura ( )
Order 1. Opisthobranchia ( )
Order 2. Pulmonata ( )

Class III. Scaphopoda ( )

Class IV. Pelecypoda ( )
Order 1. Protobranchia ( )
Order 2. Filibranchia ( )
Order 3. Eulamellibranchia ( )
Order 4. Septibranchia ( )

Class V. Cephalopoda ( )
Order 1. Tetrabranchia ( )
Order 2. Dibranchia ( )

PHYLUM X. ARTHROPODA

Class I. Crustacea ( )
Subclass 1. Branchiopoda ( )
Subclass 2. Ostracoda ( )
Subclass 3. Copepoda ( )
Subclass 4. Cirripedia ( )
Subclass 5. Leptostraca ( )
Subclass 6. Malacostraca ( )

Class II. Merostomata ( )
Order 1. Gigantostraca)

Class III. Poecilopoda ( )
Order 1. Xiphosura ( )

Class IV. Linguatulida ( )
Order 1. Pentastomoidea ( )

Class V. Pantopoda ( )
Order 1. Clossendromorpha ( )
Order 2. Nymphomorpha)
Order 3. Pycnogomorpha ( )

Class VI. Arachnoidea ( )
Subclass 1. Cteiphora ( )
Order 1. Scorpiones ( )

Subclass 2. Lipoctena ( )
Order 1. Pedipalpi ( )
Order 2. Araneae ( )
Order 3. Meridogastres ( )
Order 4. Opiliones ( )
Order 5. Acarina ( )
Order 6. Cheloneti ( )
Order 7. Solifugae ( )

Class VII. Myriapoda ( )
Subclass 1. Opisthogoneata ( )
Order 1. Chilopoda ( )

Subclass 2. Progoneata ( )
Order 1. Symphyla ( )
Order 2. Pauropoda ( )
Order 3. Diplopoda ( )

Class VIII. Mirientomata ( )
Order 1. Protura ( )

Class IX. Collembola ( )
Order 1. Arthropleona ( )
Order 2. Symphopleona ( )

Class X. Campodeoidea ( )
Order 1. Rhabdura ( )
Order 2. Dicellura ( )

Class XI. Thysanura ( )
Order 1. Lepismatoidea ( )
Order 2. Machiloidea ( )

Class XII. Pterygogenea (Insecta sensu stricto), ( )

Subclass 1. Orthopteroidea ( )
Order 1. Grylloblattoidea ( )
Order 2. Orthoptera ( )
Order 3. Phasmoidea ( )
Order 4. Diploglossata ( )
Order 5. Dermaptera ( )
Order 6. Thysanoptera ( )

Subclass 2. Blattaeformia ( )
Order 7. Mantoidea ( )
Order 8. Blattoidea ( )
Order 9. Zoraptera ( )
Order 10. Isoptera ( )
Order 11. Corrodentia ( )
Order 12. Mallophaga ( )

Order 13. Siphunculata ( )

Subclass 3. Hymenoptera ( )
Order 14. Hymenoptera ( )

Subclass 4. Coleopteroidea ( )
Order 15. Coleoptera ( )
Order 16. Strepsiptera ( )

Subclass 5. Embidaria ( )
Order 17. Embiidina ( )

Subclass 6. Libelluloidea ( )
Order 18. Odonata ( )

Subclass 7. Ephemeroidea ( )
Order 19. Plectoptera ( )

Subclass 8. Perloidea ( )
Order 20. Plecoptera ( )

Subclass 9. Neuropteroidea ( )
Order 21. Megaloptera ( )
Order 22. Raphidoidea ( )
Order 23. Neuroptera ( )

Subclass 10. Panorpoidea ( )
Order 24. Panorpatae ( )
Order 25. Trichoptera ( )
Order 26. Lepidoptera ( )

Order 27. Diptera ( )
Order 28. Suctoria ( )

Subclass 11. Rhynchota ( )
Order 29. Homoptera ( )
Order 30. Hemiptera ( )

GROUPS OF INVERTEBRATES OF MORE OR LESS UNCERTAIN SYSTEMATIC POSITION

Group 1. Mesozoa)
Group 2. Nemertinea ( )
Group 3. Nematomorpha ( )
Group 4. Acanthocephala ( )
Group 5. Chaetognatha ( )
Group 6. Rotifera ( )
Group 7. Bryozoa ( )
Group 8. Phoronidea ( )
Group 9. Brachiopoda ( )
Group 10. Gephyrea ( )

PHYLUM XI. CHORDATA

Subphylum I. Cephalochorda or Adelochorda ( )

Subphylum II. Urochordata or Tunicata ( )
Order 1. Larvacea ( )
Order 2. Ascidiacea ( )
Order 3. Thaliacea ( )

Subphylum III. Hemichordata ( )
Order 1. Enteropneusta ( )
Order 2. Pterobranchiata ( )
Order 3. Phoronidia ( )

Subphylum IV. Vertebrata or Craniata ( )

Class I. Cyclostomata ( )
Subclass 1. Myxinoidea ( )
Subclass 2. Petromyzontia ( )

Class II. Pisces or Gnathostomata ( )
Subclass 1. Elasmobranchii ( )
Order 1. Plagiostomi ( )
Suborder I. Selachii ( )
Suborder II. Batoidei ( )
Order 2. Holocephali ( )

Subclass II. Teleostomi ( )
Order 1. Crossopterygii ( )
Order 2. Chondrostei ( )
Order 3. Holostei ( )
Order 4. Teleostei ( )
Subclass III. Dipneusti (Dipnoi), ( )

Class III. Amphibia ( )
Subclass I. Stegocephali ( )
Subclass II. Lissamphibia ( )
Order 1. Apoda (Gymnophiona), ( )
Order 2. Urodela ( )
Order 3. Anura ( )

Class IV. Reptilia ( )
Order 1. Chelonia ( )
Order 2. Crocodilia ( )
Order 3. Sauria (Squamata), ( )
Division I. Lacertilia ( )
Division II. Ophidia ( )

Class V. Aves ( )
Subclass I. Archaeornithes ( )
Subclass II. Neornithes ( )
Order 1. Hesperornithiformes ( )
Order 2. Ichthyornithiformes ( )
Order 3. Struthioniformes ( )
Order 4. Rheiformes ( )
Order 5. Casuariiformes ( )
Order 6. Crypturiformes ( )
Order 7. Dinornithiformes ( )
Order 8. Aepyornithiformes ( )
Order 9. Apterygiformes ( )
Order 10. Sphenisciformes ( )
Order 11. Colymbiformes ( )
Order 12. Procellariiformes ( )
Order 13. Ciconiiformes ( )
Order 14. Anseriformes ( )
Order 15. Falconiformes ( )
Order 16. Galliformes ( )
Order 17. Gruiformes ( )
Order 18. Charadriiformes ( )
Order 19. Cuculiformes ( )
Order 20. Coraciiformes ( )
Order 21. Passeriformes ( )

Class VI. Mammalia ( )

Subclass I. Prototheria ( )
  Order 1. Monotremata ( )
Subclass II. Eutheria ( )
Division I. Didelphia ( )
  Order 1. Marsupialia ( )
Division II. Monodelphia ( )

Section A. Unguiculata ( )
  Order 1. Insectivora ( )
  Order 2. Dermoptera ( )
  Order 3. Chiroptera ( )
  Order 4. Carnivora ( )
  Order 5. Rodentia ( )
  Order 6. Edentata ( )
  Order 7. Pholidota ( )
  Order 8. Tubulidentata ( )

Section B. Primates ( )
  Order 9. Primates ( )

Section C. Ungulata ( )
  Order 10. Artiodactyla ( )
  Order 11. Perissodactyla ( )
  Order 12. Proboscidea ( )
  Order 13. Sirenia ( )
  Order 14. Hyracoidea ( )

Section D. Cetacea ( )
  Order 15. Odontoceti ( )
  Order 16. Mystacoceti ( )

BRIEF CHARACTERIZATIONS OF THE MAJOR GROUPS OF ANIMALS

The principal groups of animals are given below with brief diagnoses which may serve as definitions. It must be understood that the characters given will often not be sufficient to distinguish all the forms in a group, for there is much variation within the groups. They are intended to give the student a general conception of the phyla, subphyla and classes.

Phylum PROTOZOA ( ). Single celled animals without true organs or true tissues. If colonial, the cells are all potentially alike.

Class RHIZOPODA ( ). Protozoa with changeable protoplasmic processes (pseudopodia). Amoeba.

Class MASTIGOPHORA ( ). Protozoa with one or more vibratile processes (flagella) which serve for locomotion and for taking food. Euglena.

Class SPOROZOA ( ). Parasitic Protozoa, usually without motile organs or mouth, reproducing by spores.

Class INFUSORIA ( ). Protozoa having numerous slender vibratile processes (cilia), a cuticle, and fixed openings for the ingestion of food and the extrusion of indigestible matter. Paramoecium.

Phylum PORIFERA ( ). Diploblastic, radially symmetrical animals with body wall penetrated by numerous pores. Body usually supported by a skeleton of spicules or spongin. Sponges.

Class CALCAREA ( ). Sponges with spicules composed of calcium carbonate, monaxon or tetraxon in form.

Class HEXACTINELLIDA ( ). Sponges with spicules composed of silicon, triaxon in form.

Class DEMOSPONGIAE ( ). Sponges with spicules composed of silicon, not triaxon in form, or skeleton composed of spongin, or with skeleton of both spicules and spongin.

Phylum COELENTERATA ( ). Diploblastic, radially symmetrical animals with tentacles, stinging cells, single gastrovascular cavity, no anus. Two body forms are prevalent, the hydroid and the medusa. Jellyfishes, polyps and corals.

Class HYDROZOA ( ). Coelenterates without stomodaeum and mesenteries; sexual cells discharged to the exterior; hydroid and medusa forms in the life history of same species, or only the medusa, the latter having a velum. Polyps (including Hydra), a few corals, small jellyfishes.

Class SCYPHOZOA ( ). Coelenterates with only the medusoid, not hydroid form; velum lacking; notches at margin of umbrella. Larger jellyfishes.

Class ANTHOZOA ( ). Coelenterates without medusoid forms, with well developed stomodaeum and mesenteries. Sea anemones, most corals.

Phylum CTENOPHORA ( ). Tripoblastic animals; symmetry partly radial, partly bilateral; eight rows of vibratile plates radially arranged. Sea walnuts or comb jellies.

Phylum PLATYHELMINTHES ( ). Triploblastic, bilaterally symmetrical animals with body flattened, with a single gastrovascular cavity (sometimes wanting) and no anus. Flatworms.

Class TURBELLARIA ( ). Free-living flatworms with ciliated epidermis. Planaria.

Class TREMATODA ( ). Parasitic flatworms without cilia but with a hardened ectoderm, usually parasitic and with attaching suckers. Flukes.

Class CESTODA ( ). Parasitic flatworms with the body differentiated into a head (scolex) and a chain of similar joints (proglottides), the whole being usually regarded as a colony. Tapeworms.

Phylum NEMATHELMINTHES ( ). Bilaterally symmetrical, triploblastic animals with an elongated cylindrical body covered with a cuticle, with a true body cavity, and a digestive tract with both mouth and anus. Roundworms.

Phylum ECHINODERMATA ( ). Radially symmetrical (with minor exceptions), triploblastic animals with well developed coelom, and usually with five antimeres, spiny skeleton of calcareous plates, and organs of locomotion known as "tube feet" operated by a water-vascular system. Starfishes, sea urchins, sea cucumbers.

Class ASTEROIDEA ( ). Free-living, typically pentamerous echinoderms with wide arms not sharply marked off from disc and with ambulacral grooves. Starfishes.

Class OPHIUROIDEA ( ). Free-living, typically pentamerous echinoderms with slender arms sharply marked off from disc and no ambulacral grooves. Brittle stars.

Class ECHINOIDEA ( ). Free-living, pentamerous echinoderms without arms; the outer covering composed of calcareous plates bearing movable spines. Sea urchins, sand dollars.

Class HOLOTHURIOIDEA ( ). Free-living, elongated, soft-bodied echinoderms with muscular body wall and tentacles around mouth. Sea cucumbers.

Class CRINOIDEA ( ). Sessile echinoderms with five arms generally branched with pinnules, aboral pole usually with cirri, sometimes with jointed stalk for attachment to substratum. Feather stars, sea lilies.

Phylum ANNELIDA ( ). Triploblastic, bilaterally symmetrical elongated animals with external and internal segmentation; coelom usually present; setae common. True worms.

Class ARCHIANNELIDA ( ). Marine Annelida with no setae nor parapodia.

Class CHAETOPODA ( ). Annelida with setae and a perivisceral coelom; marine, fresh-water, or terrestrial in habitat. Earthworms.

Class HIRUDINEA ( ). Annelida without setae, and with anterior and posterior suckers. Leeches.

Class ONYCOPHORA ( ). Annelida breathing by means of tracheal tufts, numbering from 10 to 40 per segment in irregular arrangement, with non-jointed papillate legs, nerve cords ventro-lateral, and without segmental ganglia, eyes of vesicular, annelid type, skin with chitin. This group is often placed with the Arthropoda, or as a separate phylum Proarthropoda, since its members have developed somewhat in the Arthropodan direction. Lankester thinks their evolution is as follows:

Group Articulata

1. Rotifera to Tardigrada
2. Chaetopoda
   a. Proarthropoda (Peripatus) developing independently.
   b. Crustacea—separate origin from Chaetopoda.
   From Crustacea by separate origin
   a. Myriapoda
   b. Insecta
   c. Arachnida.

Paleontologists such as Walcott, the specialist on trilobites and worms, derive all Arthropoda classes by separate lines from trilobites.

Phylum MOLLUSCA ( ). Triploblastic, bilaterally symmetrical (symmetry often obscured) unsegmented animals with a coelom, a muscular foot and usually a shell. Mollusks.

Class AMPHINEURA ( ). Mollusks with obvious bilateral symmetry, sometimes an eight-parted calcareous shell and several pairs of gills.

Class GASTROPODA ( ). Mollusks with a head and with bilateral symmetry usually obscured by a spiral shell of one piece. Snails.

Class SCAPHOPODA ( ). Mollusks with conical tubular shell and mantle.

Class PELECYPODA ( ). Mollusks without a head, with bilateral symmetry, a shell of two lateral valves and a mantle of two lobes. Clams, mussels.

Class CEPHALOPODA ( ). Mollusks with distinct bilateral symmetry and a foot bearing eyes and divided into arms usually with suckers. Cuttlefishes, octopods.

Phylum ARTHROPODA ( ). Triploblastic, bilaterally symmetrical, segmented animals with usually more or less dissimilar somites, a coelom very much reduced, paired jointed appendages, and chitinous exoskeleton.

Class CRUSTACEA ( ). Arthropods breathing by means of gills, two pairs of antennae, Crayfishes, crabs, shrimps. Certain terrestrial species with tracheae (Oniscidae—sowbugs).

Class MEROSTOMATA ( ). Fossil Arthropoda of gigantic size (2 meters in length), without antennae, short cephalothorax, 12-segments in abdomen, and pointed telson. Eurypterus.

Class POECILOPODA ( ). Arthropoda with large shield-shaped cephalothorax, abdomen with six pair lamellate legs, with extremely long pointed telson. Limulus, king crabs.

Class **LINGUATULIDA** ( ). Parasitic Arthropoda (Pentostomidae) of worm-like build, body with metameric circular muscles, two pairs of hooks in region of mouth, mouth without mandibles. Affinities uncertain.

Class **PANTOPODA** ( ). Marine Arthropoda, body segmented, abdomen vestigial, with not more than seven pairs of legs, mouth a beak.

Class **ARACHNOIDEA** ( ). Arthropods with either tracheae, book lungs or book gills, or both, and no antennae. Harvest-men, spiders, mites, ticks, scorpions.

Class **MYRIAPODA** ( ). Arthropods with distinct head, one pair antennae, breathing through tracheae, whose stigmata are placed in linear metameric arrangement, many legs. Myriapods and millipeds, centipeds.

Class **MIRIENTOMATA** ( ). Minute microscopic Arthropoda (600-1600 micra), with six legs, a three-segmented thorax (?), no antennae, post-embryonic increase of segments, first pair of legs transformed into sense organ. These minute forms were only recently discovered, and their affinity is uncertain.

Class **COLLEMBOLA** ( ). Arthropods with 6-segmented abdomen, no post-embryonic increase in segments, one-jointed tarsi, few tracheae, these opening in one pair of stigmata at the throat, abdomen generally with spring. Spring-tails.

Class **CAMPODEOIDEA** ( ). Arthropods with long body, abdomen 10 segments, with cerci. No eyes, mouth-parts withdrawn, no post-embryonic change in abdominal segments. Spring-tails.

Class **THYSANURA** ( ). Arthropods with free mouth-parts and palpi, three caudal appendages, abdomen 11 segments and covered with silvery scales, frequently with spring beneath. Silver fish, fish moths.

Class **PTERYGOGENEA** ( ). Insecta, Hexopoda. Winged Arthropods, with three pairs of legs, embryos with 12 segments to abdomen, adults with all degrees of post-embryonic reduction from 12 to 6 segments. Breathe through tracheae, stigmata linear and metameric in arrangements. **True insects—i. e., winged Arthropods.**

Phylum **CHORDATA** ( ). Animals having at some time during their life's history a notochord lying between the nervous system and the alimentary tract, a hollow central nervous system lying entirely on one side of the digestive canal, and pharyngeal slits extending from the pharynx to the exterior.

Subphylum **CEPHALOCHORDA** or **ADELOCHORDA** ( ). Fish-like chordates with a permanent notochord composed of vacuolated cells, such as **Amphioxus.**

Subphylum **UROCHORDATA** or **TUNICATA** ( ). Sac-like marine animals with a cuticular covering known as a tunic or test. This group possesses a notochord only in the caudal region. Example, **Tunicates.**

Subphylum HEMICHORDATA ( ). Worm-like chordates of doubtful systematic position. There is a projection from the mid-dorsal region of the alimentary canal similar to a notochord. These animals possess a collar and a proboscis. Example, **Balanoglossus.**

Subphylum CRANIATA or **VERTEBRATA** ( ). Chordates in which the notochord either persists or becomes invested with cartilage. Vertebrates have a segmented spinal column.

Class CYCLOSTOMATA ( ). Eel-like vertebrates without functional jaws or lateral appendages. Examples, hagfishes and lampreys.

Class PISCES or **GNATHOSTOMATA** ( ). Fishes with a lower jaw and paired pectoral and pelvic fins, scales and paired nostrils. The heart has an auricle, a ventricle, a conus arteriosus and a sinus venosus.

Class AMPHIBIA ( ). Cold-blood vertebrates breathing by means of gills at some stage of their life-cycle. Skin not usually covered with scales. Three chambers in heart beside the conus arteriosus and sinus venosus. Frogs, toads, newts, and salamanders.

Class REPTILIA ( ). Cold-blooded vertebrates breathing by means of lungs throughout their life-cycle. Usually covered with scales. Lizards, snakes, crocodilians, and turtles.

Class AVES ( ). Warm-blooded vertebrates, whose body is usually covered with feathers and the fore-limbs modified for wings. Heart of four chambers. Birds.

Class MAMMALIA ( ). Warm-blooded animals with hair covering at some stage in their life-cycle. They suckle their young and have a diaphragm between thorax and abdomen.

Subclass PROTOTHERIA ( ). Egg-laying mammals. Example, monotremes, such as the Australian duck-bill.

Subclass EUTHERIA ( ). Mammals which give birth to living young. These are the true mammals.

Division DIDELPHIA or **METATHERIA** ( ). These are the marsupials, such as the opossum and kangaroo.

Division MONODELPHIA ( ). These are the placental animals which are nourished in the body of the mother through a true placenta.

INVERTEBRATE GROUPS OF UNCERTAIN POSITION

Certain groups of invertebrates have not been assigned a definite relation to other groups. Opinion differs so widely as to their affinities that they may well be kept out of the classification for the present.

Mesozoa. Parasites apparently intermediate between the Protozoa and Metazoa. Not improbably degenerate relatives of the flatworms.

Nemertinea. Terrestrial, fresh water and marine animals resembling flatworms but with a proboscis, blood vascular system, and alimentary canal with two openings.

Nematomorpha. Long thread-like animals with the body cavity lined with epithelium, a pharyngeal nerve ring and a single ventral nerve cord.

Acanthocephala. Parasitic worms with spiny proboscis, a complex reproductive system and no alimentary canal.

Chaetognatha. Marine invertebrates with a distinct coelom, alimentary canal, nervous system and two eyes.

Rotifera. Invertebrates with a head provided with cilia, usually a cylindrical or conical body often with a shell-like covering, and a bifurcated tail or foot provided with a cement gland.

Bryozoa. Mostly colonial invertebrates resembling hydroids in form, with distinct coelom, and with digestive tract bent in the form of a letter U.

Phoronidea. A single genus of worm-like animals having tentacles and living in membranous tubes in the sand.

Brachiopoda. Marine tentaculate animals with a calcareous shell, composed of two unequal shell-parts (commonly called valves), a dorsal and a ventral.

Gephyrea. Worm-like animals of doubtful affinities.

Part II

Introductory Embryology

(Chick, Frog, and Mammal)

CHAPTER XXIX.

EMBRYOLOGY OF THE CHICK

THE DEVELOPMENT OF THE EMBRYO BEFORE THE EGG IS LAID

Before beginning the work proper in **Introductory Embryology** it is quite essential that the student turn back to earlier Chapters and reread what is said there on **mitosis, fertilization,** and the **histology** of the frog. Such a review will lay a foundation for the detailed study of the following pages.

When we come to take up Comparative Anatomy in the next semester's work, it will be found that the Haeckelian law of biogenesis (also called the "recapitulation theory"), although untrue in its usual application, is a very convenient supposition in that it makes many points clear if we accept it as a working hypothesis. This so-called law is defined as follows: All animals, during their embryonic period, pass through the same adult-stages that the various members of the race to which they belong have passed. For practical purposes it is necessary to keep this theory in mind in the study of embryology; for, it is the simplest way of bringing home to the student the fact, that in any biological study that is to be scientific, one must first study the more simple organisms and then compare such simple forms with those that are more complex—the so-called higher forms.

All living animals pass through a quite similar stage of development in their embryonic period, so that the next succeeding higher form practically possesses everything that the immediately next succeeding lower form possesses, **plus something additional.** And it is this "plus something" that we are trying to arrange in proper order when we study embryology.

The value of this is not always clear to the student, but if he will remember that a human being and a chick pass through quite similar stages during their embryonic periods, the human being, however, developing further, he can understand how an obstruction may prevent any individual part of an organism from receiving the proper nourishment and environment, and thus cause such part to cease developing, thereby producing what is called a rudimentary structure. (Fig. 250.)

Now, while all animals differ slightly from each other, there are certain **type-forms,** in which the greatest differences can be clearly observed. Such type-forms as commonly used in the laboratory are the **dog-fish,** as a representative of the cartilaginous fishes; the **frog,** as an example of amphibia; the **chick** or **pigeon,** as an example of birds; the **turtle,** as an example of reptilia; and the **cat, rabbit,** or **pig,** as an example of the mammals.

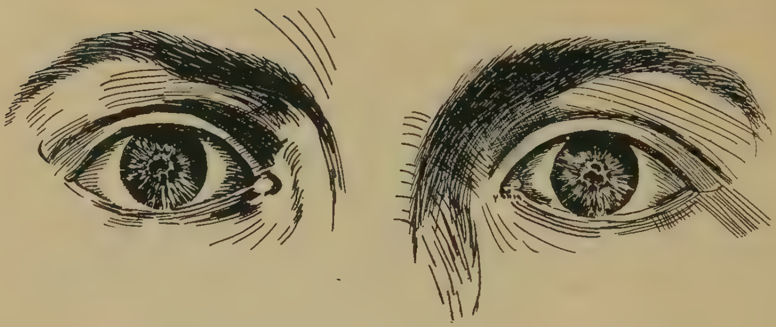


Fig. 250.

There is a membrane covering the pupil of the eye which, in man, normally disappears when the embryo is seven months old. In the case here shown portions of the membrane have persisted as an irregular network over the pupil. Such persistent structures are called rudimentary. (From a drawing lent by Dr. G. N. Brazeau.)

As we have been using the frog as a norm, or **standard type,** with which to compare the other forms studied, it would probably seem best to begin embryology with that animal. However, for the same reason that the frog was used as an introductory subject for study (because it can be procured easily and because it is a fairly complex form which possesses structures with which the student is already familiar), so, the hen's egg, which is much larger than that of the frog, can also be procured easily and is already somewhat familiar to the student. And in addition to this, the chick embryo develops upon the surface of the yolk, which makes the various germ layers very distinct, thus serving much better than the frog as a beginning-type.

The first and foremost point in the study of embryology is **accuracy of observation**; the second is the obtaining of a clear and understandable **concept** of what has been observed; and the third point is to show by **drawings** that the first and second have been fully grasped.

There is considerable need for legitimate imagination in embryological work, because the entire study of embryology is for the purpose of giving the student a more or less comprehensive idea of the process through which, and by which, all the organ-systems in the body of living things **have come to be what they are.** The study of embryology is therefore different from our later work in pure anatomy, where each structure is definite, and where such structure is studied only after it is completely formed. In embryology we see the beginnings and development of these later anatomical structures.

One should first take the **complete embryo**, and get a good grasp of the general structure. Then, **sections** must be cut at various intervals and studied microscopically. It must never be forgotten, however, that our imagination must constantly remind us that there are three dimensions to the living animal, and that what we are looking at in our section, is but a series of **still pictures,** and that there is little value or meaning in such observation unless one can, with **imagination and logic,** plus **preceding biological knowledge,** build up a completed structure, so that the mind's eye can see the entire animal as it actually is.

It must be remembered at this point that events which have already taken place in the past, are the cause or causes of events that are now taking place, and that will take place later. This is as true in embryology as it is in such a study as history, for example. This means that the various events of development are caused by preceding developmental events and that these cause later steps in development in turn.

Another important point for the student to remember is that he must not only be able to recognize histologically the **type of cells** he may find in the section he is studying, but he must know the **definite location** in the complete embryo from which his section is cut.

The complete bird-like form of the chick can be clearly seen before the eighth day of incubation, all the principal changes having taken place by that time. It will, therefore, be understood that these changes are rather minute in their origins, for the eight-day embryo is only about seven millimeters in length. During, and after the eighth day, the changes which take place are primarily enlargements, or growth of portions already present.

In the study of embryology we are not only interested in the development of the chick from the egg, but we also wish to know how the egg came into existence.

The hen's egg is usually said to be a single cell. This is, however, only true if the egg is unfertilized.

As birds' eggs are laid with shells upon them, it is necessary that fertilization take place before the shell is formed. Fertilization in these cases is **internal.** It takes about twenty-two hours for the egg to have the various layers of yolk and white laid down, and for the shell then to surround it. If the egg has been fertilized, the warmth of the mother's body has already caused development throughout these days, so that by the time the egg is laid, the little chick is already approximately two, or two and a half, days of age. There is a variation in the age because if the hen's egg is ready for laying during the main part of the day, it is laid then, but if it is not ready for laying until, let us say, about four or five o'clock in the afternoon, it is retained within the mother's body until the following day, thus causing some embryos to be developed from ten to fifteen hours more than others.

The so-called spoiling of eggs is usually due to the embryo chick dying and then decaying.

In birds, where the eggs leave the mother's body, the yolk must be quite large in order to furnish sufficient food for the embryo during the two or three weeks intervening between the time the egg leaves the mother's body and the time of hatching. In the viviparous animals, the egg remains extremely small because the nourishment of the embryo is derived directly from the mother.

During the very first day of incubation the outlines of the embryo are defined. During the second day a rather complicated series of folds appear, separating the embryo from the yolk. The embryo, however, remains in contact with the yolk-mass by a narrow stalk. The circulatory system now develops, through which nourishment is carried from the yolk-mass to the embryo. Embryonic membranes and appendages appear during the second and third days of incubation. These assist in respiration and also in forming a larger area from which the food supply may be brought from the yolk to the embryo.

Development usually begins at the head end and extends tailward, so that the brain and other head structures are often quite well developed when there is little semblance of any other well-defined structure toward the tail end. The chick usually makes a small opening in the egg shell on about the twentieth day of incubation, and from then on the lungs actually take in air and begin their regular external work, while on the twenty-first day the chick breaks through the shell entirely.

With this introductory general outline, we shall take up the study of the egg itself, working backward to its very simplest cell origin in the mother's ovary.

THE EGG

The true ovum (Fig. 251, v), or egg-cell proper, is the large yolk or vitellum. This is surrounded by a tough vitelline membrane. The

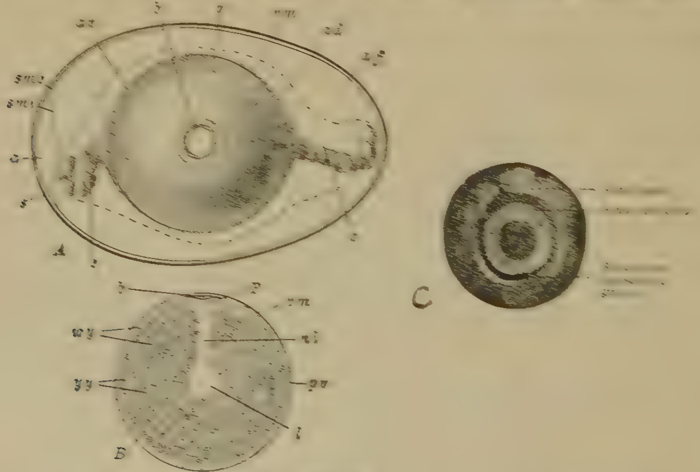


Fig. 251.

Semidiagrammatic illustration of the hen's egg at the time of laying. A. Entire "egg." B. Diagram of a vertical section through the vitellus or ovum proper, showing the concentric layers of white and yellow yolk. a. Air chamber; ac. chalaziferous layer of albumen; ad. dense layer of albumen; al. fluid layer of albumen; b. blastoderm; c. chalaza; l. latebra; nl. neck of latebra; p. nucleus of Pander; pv. perivitelline space; smi. inner layer of shell membrane; sme. outer layer of shell membrane; v. vitellus or "yolk"; vm. vitelline membrane; wy. layers of white yolk; yy. layers of yellow yolk. C. Surface view of blastoderm of unincubated hen's egg. (A and B, after Marshall; C, after Hertwig.)

end of the ovum, where the embryo is to develop, is called the **animal pole.** It is nearly free from yolk, and appears at the time of laying as a circular whitish area known as the **blastoderm** (Fig. 251, b), and measures from three to four millimeters in diameter. As the animal pole is not as dense as the surrounding material, it is always found on top of the yolk, no matter which way the entire egg be turned, provided, of course, that the yolk is free to rotate.

The more central portion of the animal pole is rather translucent or **pellucid** and therefore is called the **area pellucida** (Fig. 251, C). This central portion is surrounded by a whitish or **opaque region** called the **area opaca.** The yolk itself is called **deutoplasm,** and is divided into two types of material, **white and yellow yolk.** The white yolk occupies the region just below the blastoderm, and is rather shaped like a flask, as shown in the figure. It extends to the center of the yolk. It will be noticed that the yolk is thus arranged in various **concentric layers.** A layer of thick yellow yolk alternates with a thinner stratum of white yolk. The two types of yolk differ in physical characteristics and in chemical composition.

The vitellus or true egg-cell alone is formed in the ovary. Such structures as develop within the ovary proper are called **primary.** Structures, such as **chorionic membranes** (found in most of the higher forms), are known as **secondary** structures, while those particular regions which are formed by **accessory reproductive organs,** such as the white of the egg and the shell, are said to be **tertiary structures.** The white of the egg is composed of albuminous matter which is chemically quite complex. It will be remembered that the protoplasm in all living cells is largely albuminous.

Toward each end of the newly-laid egg, one finds a dense, opaque twisted cord extending through the white of the egg from opposite sides of the yolk toward the apices of the shell. These twisted cords are called **chalazae** (Fig. 251, C). They are continuous with a very thin, dense layer of albumen surrounding the yolk. This thin layer is called the **chalaziferous layer.** It is generally assumed that the chalazae assist in holding the yolk in position, though this has been disputed by several biologists, primarly because the ends nearest the shell are not attached. Immediately outside the chalaziferous layer there is another thick, dense layer of albumen, and superficial to this is a still thicker layer of a more fluid albumen. The hard-boiled egg in which the albumen has coagulated lends itself well for the observation of these various layers. Usually, in observing such hard-boiled eggs the albumen is seen to be arranged in **spiral sheets.**

The ovoid shell which surrounds the entire egg is quite resistant to gradually applied pressure, but easily broken if the blow be sharp. The shell in turn is covered superficially by a thin cuticle perforated by many pores. The main substance of the shell is made up of loosely arranged particles of carbonates and phosphates of calcium and magnesium. The inner surface of the shell is composed of a thin but dense layer of inorganic salts. After the shell has dried, it is quite porous, thus making the passing of gases and water-vapor quite easy.

There is a tough **shell membrane** lining the inner portion of the shell. It is composed of a double sheet of fibrous connective tissue which separates at the blunt end of the egg into an air space, becoming larger as time goes by.

THE REPRODUCTIVE ORGANS OF THE FOWL

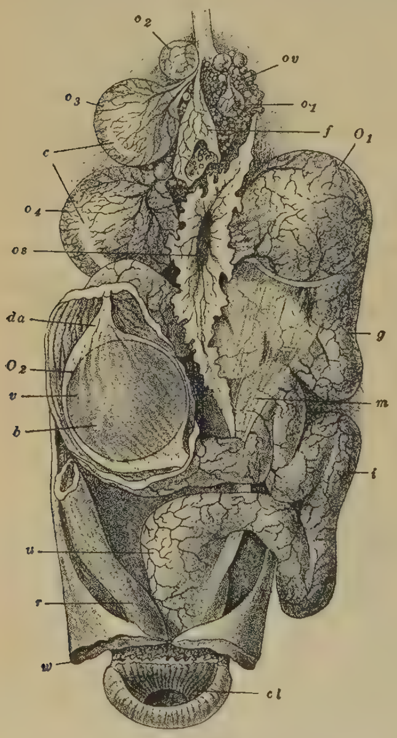


Fig. 252.

The reproductive system of the fowl. The figure shows two eggs in the oviduct, whereas normally only one egg is in the oviduct at a time. *b*, Blastoderm; *c*, cicatrix; *cl*, cloaca; *da*, dense layer of albumen; *f*, empty egg follicle from which the ovum has escaped; *g*, glandular portion of oviduct; *i*, isthmus; *m*, mesovarium; o_1-o_4, ovarian ova in various stages of growth; O_1, ovum in upper end of oviduct; O_2, ovum in middle portion of oviduct (the oviduct has been cut open to show the structure of this ovum) ;*os*, ostium or infundibulum; *ov*, ovary containing ova in various stages of growth; *r*, rectum; *u*, uterus; *v*, vitellus; *w*, ventral body wall, opened and reflected. (From Duval.)

One obtains a more thorough understanding of the development of the egg in the ovary if a review of the entire reproductive organs is undertaken. The reproductive organs of the fowl do not develop equally on each side, though they begin developing symmetrically. The right ovary ultimately degenerates, and as far as we know does not function. The **left ovary** (Fig. 252) **and oviduct alone carry on the work of the organs.** The left organs therefore become quite large.

A microscopical section of the ovary shows this organ to be composed of a great quantity of **ova,** each ovum being contained in a **Graafian follicle** (Fig. 253). The ovary itself is suspended from the dorsal abdominal wall by a double fold of the peritoneum called a **mesovarium.**

In the hen, the ova vary in size from a very small cell up to the full sized yolk. The **oviduct** is large, thick-walled and muscular, being convoluted, and having a different structural form in the different parts. As the oviduct is to carry eggs from the ovary to the **uterus,** there are two openings, one the abdominal, which is rather wide and flaring and funnel-shaped, coming in close contact with the ovary. This opening is called the **ostium** or **infundibulum,** or the **fimbriated** opening. This last name is due to its fringe-like margin. This region is thin and muscular and lined with cilia. The oviduct proper into which the ostium leads is known as the **convoluted glandular portion,** which is followed by a short, third portion called the **isthmus.** It is after passing through the isthmus that the egg enters the so-called **uterus,** which is merely a dilated portion of the glandular tube. The uterus in turn opens into a short **terminal region,** a rather thin-walled **vagina,** and this again opens into the **cloaca,** just dorsal to the opening of the rectum.

It is easier for the student to understand a developmental history of the egg if it be thought of as passing through three periods. First, from the beginning of the development of the ovum to the time of **ovulation.** Second, from the time of ovulation through the period of **fertilization,** and third, from the beginning of **cleavage** to the time the egg is laid.

First Period. (From the beginning of the development of the egg to the time of ovulation.) Most animals produce a large number of eggs within a very brief period, while in the hen there is a long period of egg formation and laying, which extends over several months, after which there is a period of almost complete cessation. Undoubtedly the reason for this is that when an egg becomes as large as that of the hen, which requires so much food in its making, it is a considerable drain upon the animal, and secondarily, there isn't room enough in the body of an animal no larger than a hen for many eggs of such size. However, the fact that the hen's ova develop in the way they do, makes it possible for us to observe almost a complete succession of developmental changes from the minute forms up to the fully developed egg.

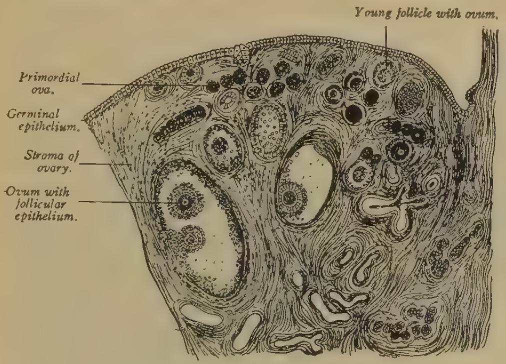


Fig. 253.

Section from ovary of adult dog. The more or less star-shaped figure on the right is a collapsed follicle with its contents. Below and at the right are seen the tubules of the Parovarium. (After Waldeyer.)

In our course of general biology, we learned that very early in an organism, especially in triploblastic forms, the germplasm and somatoplasm differentiate. A few cells are set aside in the innermost portion of the body of the growing embryo for reproductive purposes. The development in the growing embryo of the germplasm is called **oögenesis** in the female, and **spermatogenesis** in the male. It will also be remembered that all the eggs are already present in the ovary at the time the female is born.

OÖGENESIS

The process by which the eggs already present in the ovary of the new-born chick originally came to be what they are is known as **oögenesis.** The first event in oögenesis is known as the **multiplication of the oögonia.** This occurs during the embryonic period of the animal. There are two types of cells which develop from the original primary cells set aside for reproductive purposes. How and why these differentiate in the way they do we do not know, but we do know that there is a differentiation.

As soon as these original cells commence to divide, some of them develop into centrally located eggs or ova (Fig. 254), while others, known as **germinal epithelium,** surround the more centrally located ova and form a sort of case or capsule around them. The primitive egg surrounded by this epithelial case is known as an **oögonium.** Some of these leave the epithelium and pass into the stroma of the ovary. There they degenerate. Those remaining, however, begin enlarging even while they are dividing and multiplying. The epithelial cells also divide very rapidly, forming long strands or cords which in turn extend into the stroma. There comes a time when these primitive ova or oögonia stop multiplying; they are then called **primary oöcytes.** At this time the strands or cords of germinal epithelium break up into little groups sometimes called **nests.** Each nest consists of a single primary oöcyte (Fig. 255) surrounded by a number of the original epithelial cells. These latter cells form a definite case surrounding the oöcyte. The case thus formed is called the **primitive egg follicle.** This final arrangement takes place within a few days after hatching. It will thus be seen that all the eggs which enlarge, ripen, and pass out of the ovary are merely enlarged and developed primary oöcytes.

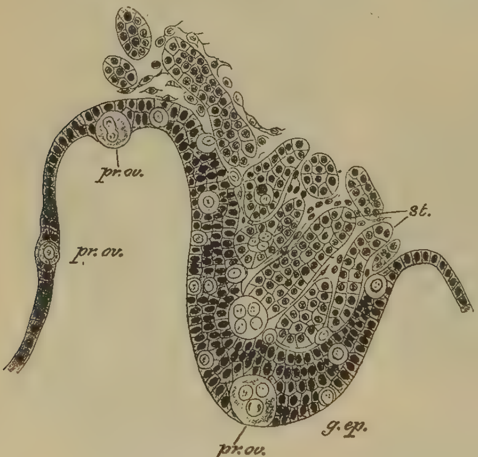


Fig. 254.

Section of the Germinal Epithelium and Adjacent Stroma in a Chick-Embryo.

g.ep., germinal epithelium forming a thickened ridge-like projection; *pr.ov.*, primitive ova of various sizes, some in the germinal epithelium and others somewhat beyond the limit of this epithelium; *st.*, strands of cells which have grown from the germinal epithelium, and one of which appears connected with an enlarged primitive ovum. (From Semon.)

Both the nucleus and the cytoplasm of the egg cell now begin to enlarge, and yolk granules are laid down all about the centrally located nucleus as well as throughout the cytoplasm, **except in the peripheral region.** This region remains comparatively free from yolk. At the point where the ovum or follicle is attached (Fig. 256), there is a thicker portion in the periphery known as the **germinal disc or spot.** As soon as the ovum reaches a diameter of about five-tenths of a millimeter, the nucleus migrates into the germinal disc, where it remains as long as the egg continues in the ovary. An important point to remember is that the animal pole of the ovum is toward the attached surface, that is, at the point where the nucleus is located.

From this time onward, the yolk accumulates very rapidly. The surface of the ovum is in the form of **zona radiata** (Fig. 256, B), in which there are many pores through which nutritive substances may easily diffuse from the follicle cells. These follicle cells may therefore be called **nurse cells.**

The manner in which we estimate the rate of growth in all final stages of the hen's egg is by the arrangement of the concentric layers of white and yellow yolk. This is possible, because layers mark daily additions in the formation of yolk or food-matter.

When the follicle has completed its growth, it becomes somewhat membranous. Directly opposite its point of attachment there are very few blood vessels, and it is at this point that a modification takes place in the form of a band appearing, known as the **cicatrix.** It is at the cicatrix that the follicle ruptures to permit the escape of the egg into the oviduct.

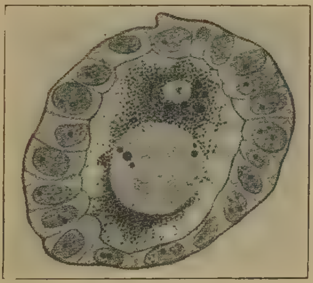


Fig. 255.

Young Oocyte surrounded by a single layer of Follicular Cells. (Van der Stricht.)

Showing attraction-sphere, centrosome, and mitochondria.

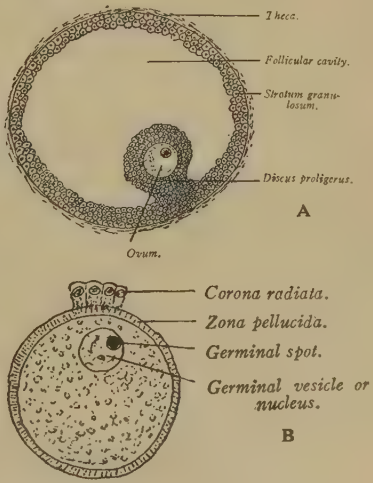


Fig. 256.

A, ripe Graafian follicle. *B*, ovum.

The nucleus lies flat against the vitelline membrane, and becomes very large just before the egg leaves the ovary. It is then called a **germinal vesicle,** because the chromatin condenses, which leaves the nucleus appearing as a large clear spot. The nuclear wall now breaks down and forms the first **polar spindle.** This rotates into position and the primary oöcyte is ready for its first maturation division, and later, for ovulation.

Second Period. (Ovulation, Maturation, and Fertilization.)

The coördination of different functions in the body is well shown by the fact that at about the time a completed egg is ready to pass into the oviduct, the region of the ostium of the oviduct becomes very active and actually seems to grasp the ovarian follicle which contains the primary oöcyte. This may be due to muscular or ciliary action or it may be a combination of both. The follicle then ruptures, permitting the egg to be thrown out. It seems that the pressure exerted by the contraction of the fringed end of the ostium may have had something to do with such rupture. The throwing of the eggs out of the follicle is called **ovulation.** The oöcyte always enters the infundibulum of the oviduct with its chief axis transverse to the long axis of the oviduct, and throughout its entire passage down the tube, this relation is retained.

After the sperm has been injected into the female, they make their way up the oviduct toward the ovary, seeming to gather at its end. They may remain alive and function for at least two weeks, sometimes even longer. It will thus be noted that as soon as the egg has been discharged from the follicle and has been taken into the oviduct, there are millions of sperm floating about in the fluid surrounding it. A single egg of the hen, unlike that in most animals, has from five to twenty-four spermatozoa enter it. Such a process is known as **polyspermy.** Polyspermy is abnormal in most animals, but it is the normal condition in the hen. The egg is now **fertilized.** The sperm apparently affords the stimulus which causes the egg to begin dividing and to form an embryo.

The egg, after the entrance of the various spermatozoa, is not yet completely mature. A process of **maturation** now takes place. This means that the egg divides into a larger and a smaller portion, both of which portions may again divide into two parts. All of the smaller portions degenerate, one large one alone developing into a complete, fertilized, hen's egg. The reason for these small **polar bodies** (as the degenerating portions are called) is that one-half of the chromatin must be lost in order that the new-born young may be a normal individual like its parent, as explained in our studies of mitosis, maturation, and genetics.

After the **second maturation division,** the remaining nucleus unites with a single sperm nucleus to form the **first cleavage spindle,** and the egg is now ready to begin dividing and form a true embryo.

Third Period. (From the Beginning of Cleavage to the time the egg is laid.)

It must be remembered here that the fertilized egg, which is to become the embryo, is present in the hen's body quite a number of hours before the egg is laid. In fact, from two to three days before the various layers of white, yolk, and shell, have encircled it. The heat from the mother's body has caused the embryo to begin to form, so that by the time the egg is laid, the embryo is already several days old. It is therefore essential that the student understands in detail, exactly what has already happened in the mother's body before the egg passes to the outer world.

The **first cleavage furrow** can be seen about three hours after the ovum has been discharged from the follicle. During this period the egg has passed along the entire glandular portion of the oviduct. The glands themselves have secreted the most dense portions of albumen and also the chalazae, it being remembered that the yolk was already laid down **before ovulation.** The egg is carried along principally by **peristaltic action** of the walls of the oviduct. Then, as the egg itself rotates, the germ disc comes to describe a spiral path, which explains the spiral arrangement of the albumen around the yolk. The egg then traverses the isthmus for approximately an hour where the shell membrane is secreted over the dense albumen. The fluid layer of albumen is secreted both in the isthmus and the upper part of the uterus. The fluid layer of the albumen passes through the shell membrane which has already been laid down, and it takes from five to seven hours after the egg enters the uterus before this is completed. But, before this takes place, the shell substance itself has already begun to be laid down on the shell membrane. Usually twelve to sixteen hours are necessary to complete the passage through the uterus and vagina. At the end of this time **twenty-one to twenty-seven hours have already elapsed since ovulation took place. Gastrulation has begun,** and the egg is laid.

We have already mentioned that if the egg reaches the vagina, ready to be laid, during the main portion of the day, it will be laid that day, but if it should be ready for laying after four or five o'clock in the afternoon, it will be retained in the vagina until the following day, thus causing some embryos in freshly-laid eggs to be approximately twelve hours older than others. It is for this reason that there is always considerable variation, even when eggs have been incubated for the same number of days.

TABLE (After Kellicott) SHOWING THE CHIEF EVENTS IN THE EARLY HISTORY OF THE HEN'S EGG

Hours after Ovulation	Location in Oviduct	Action of Oviduct	Action of Germ Disc
0	Infundibulum	Reception of Ovum	Maturation and Fertilization.
0 to 3	Glandular Portion	Secretion of chalazae, chalaziferous and dense albumen layers.	First cleavage furrow.

3 to 4	Isthmus	Secretion of shell membrane and fluid albumen.	Formation of eight cells.
4 to 21 (27)	Uterus and Vagina	Secretion of shell and fluid albumen. Retention prior to laying.	Gastrulation begun, or completed if egg is long retained.

With what has just been said in mind, the developmental processes of an embryo become more understandable. The unicellular germ disc is composed of a very definite area at the animal pole. The disc itself is about three millimeters in diameter, and less than five-tenths millimeters in thickness. Directly beneath this disc, there is a merging of the protoplasm with the white yolk. This well-marked region is called the **nucleus of Pander** (Fig. 251, P), and this connects the central white yolk by a narrow stalk called the **latebra.** It is necessary to study all the figures carefully to understand these and successive terms, and to grasp the relationship of each to the other.

There are two regions in the disc itself: the larger central portion

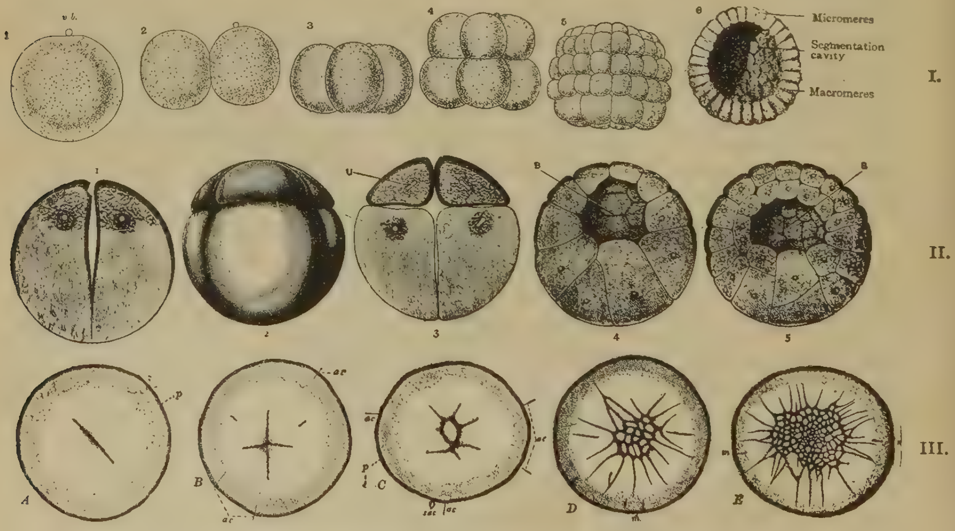


Fig. 257.

Cleavage. Upper Row, *Amphioxus.* (After Hatschek.) 1, Unfertilized egg; 2, stage of two blastomeres; 3, stage of four blastomeres; 4, stage of eight blastomeres; 5, stage of seventy-two blastomeres; 6, section of blastula; *p.b.*, polar body. Middle Row, Frog. *B*, segmentation cavity. *v*, nucleus. Lower Row, Hen's egg. (After Patterson.) Surface views of the blastoderm and the inner part of the marginal periblast only. The anterior margin of the blastodisc is toward the top of the page. *A*. Two-cell stage. About three hours after fertilization. *B*. Four cells. About three and one-fourth hours after fertilization. *C*. Eight cells. About four hours after fertilization. *D*. Thirty-four cells. About four and three-fourths hours after fertilization. *E*. One hundred and fifty-four cells upon the surface; the blastoderm averages about three cells in thickness at this stage. About seven hours after fertilization. *ac*, Accessory cleavage furrows; *m*, radial furrow; *p*, inner part of marginal periblast; *sac*, small cell formed by the accessory cleavage furrows.

which is to form the **blastoderm** proper, and the narrow denser area known as the **periblast**, which forms the outer margin. The periblast forms a continuous layer over the yolk, peripherally.

In the center of the germ disc, the first cleavage furrow appears. (Fig. 257). It is short and shallow, running about one-half the diameter of the disc. We do not even know whether the first cleavage extends directly through the central portion of the embryo. The main embryonic axis lies almost at right angles to the long axis of the whole egg, the head end of the embryo being directed toward the left when the sharp end of the egg is held pointing away from the observer. The first cleavage plane does not seem to have any definite relation to either of these axes.

The second cleavage is also vertical, and almost at right angles to the first, so that we have four adequal cells, all, however, incomplete. The third cleavage appears about an hour after the first. This is usually parallel to the first. It divides the disc into two rows of four cells each. This cleavage may be quite irregular in form, and from now on it is impossible to tell exactly how and when, in relation to time especially, these egg cells divide. Consequently, after they have divided and formed sixteen cells, all of these cells are very irregular, and there is a tendency in the fourth cleavage plane to separate the eight cells into a **central** and a **distal** one.

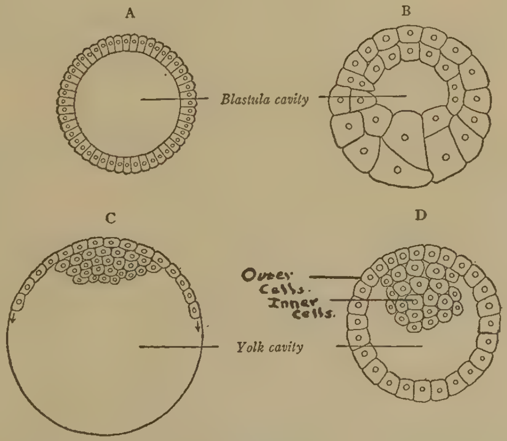


Fig. 258.
Diagrams showing the blastulæ: *A*, of Amphioxus; *B*, of frog, and *C*, of chick; *D*, blastodermic vesicle of mammal. (After Semon.)

A group of **central cells** now becomes circumscribed, but these must not be confused with the **marginal cells** which remain incomplete both below and distally, retaining their connection with the periblast. These central cells have been separated by a horizontal cleavage plane, and this cleavage plane separates the more superficial cellular elements from the underlying undivided protoplasm, leaving a little space, which is the beginning of the **segmentation cavity** or **blastocoele** (Figs. 257, II B, and 258). The undivided protoplasm beneath is called the **central periblast**, the original periblastic region being now known as the **marginal periblast**. Both of the periblastic regions retain their connection with each other peripherally in the deeper regions of the marginal cells.

The question that may arise here is, "What has become of the accessory or supernumerary spermatozoa?" Between the time of fertilization and the first cleavage, these have formed nuclei which migrated to the outlying portion of the blastodisc. There they probably divided once or twice to form small groups of daughter nuclei. There even seems to be an attempt of the cytoplasm to divide, and sometimes short superficial growths are actually formed. These are called **accessory cleavages.** They can be seen during the four and eight cell stage, usually radial in direction, lying just across or outside the margin of the blastodisc. No true cells, however, are formed by such cleavages. The accessory sperm nuclei all degenerate rather rapidly, the accessory cleavages fading away, so that by the time the embryo has reached the thirty-two cell stage, no traces of these accessory structures can be found at all.

As cleavage continues, the number of central cells increases very rapidly, by the marginal cells dividing and being added to the central cells, although the central cells divide likewise. This latter multiplication is very rapid, the cells diminishing in size. For example, cleavages appear in the central cells, causing the roof of the blastocoele to become several cells in thickness. There are no cells added to the germ disc from the floor of the segmentation cavity. The continual cutting off of central cells from the marginal cells causes these latter to be considerably shortened, until finally they are limited to the extreme margin of the blastodisc only.

After division has taken place so that two or three hundred cells have been formed, there are intercellular furrows extending out into the marginal periblast. Up to this time, there have been no nuclei whatever in either central or marginal periblast, but two areas which are continuous now become converted into a nucleated syncytium. Our knowledge of this developing process comes from the study of the pigeon. It has not been worked out in the chick. The process is somewhat like this: The marginal cells have become spherical in form, by having the central cells cut off from them. Their nuclei now divide, although the cytoplasmic divisions are either completely lacking or do not completely divide. The free nuclei therefore become quite extensive in the margin of the blastodisc, and as these nuclei continue multiplying, they wander off into the marginal periblast so that nuclei are scattered about quite thickly, though the structure itself is non-cellular. Some of the nuclei also migrate inward below the blastodisc, so that the central periblast is likewise converted into a nucleated structure with the exception of the middle area above the nucleus of Pander. This area continues to remain free from nuclei; in fact, what is later to be known as the **germ wall** is partly composed of the nucleated rim of the periblast.

The blastoderm, which is rather circular, extends radially, both on account of the growth of its own cells, and by the addition of cells from the marginal periblast. The original region of the blastodisc becomes thinner and transparent. It is then called the **area pellucida.** The circular margin which is derived from the periblast is called the **area opaca.** The ring-like periblast keeps on growing, while additional nuclei are formed peripherally. At the same time, the periblast is contributing cells to the blastoderm also, so that it steadily increases in diameter. The inner nucleated margin of the periblast, which later becomes cellular, contributes to the later extra-embryonic tissues and is called the **germ wall.** The cells of the blastoderm later extend peripherally so that they overlap the inner margin of the germ wall, to form a narrow region transitional between pellucid and opaque areas.

It should be noted here that the lower surface of the periblast is directly continuous with the yolk mass, and peripherally it is continuous with a very thin superficial tissue of protoplasm. This latter is also often referred to as a part of the germ wall.

As soon as the blastoderm has become thinned out as mentioned above, the **blastula stage** is completed.

It is well at this point partially to summarize the development through the morula and blastula stage before taking up gastrulation.

THE MORULA STAGE

While text-books usually speak of an "end" to the segmentation process, it must not be supposed that the cells of the embryo stop dividing. The whole process is continuous, and the word "end" here means only that the general process of cell-division is now "general" no longer, but that **differentiation** begins. The ending of the segmentation stage means only that one can from this period on find a grouping or aggregation of cells which are not all alike.

In eggs in which there is but little yolk, the segmentation results in a rounded, closely packed mass of embryonic cells **(blastomeres)** called a **morula.** This name has been given such a cell mass because it resembles a mulberry. This morula stage, in eggs with little yolk, corresponds to the stage in the "end" of segmentation in the chick embryo. At this time the embryo is a simple disc-shaped mass of cells, several layers in thickness. This whole mass is the **blastoderm.** It lies closely applied to the yolk.

The cells in the center of the blastoderm are smaller and quite clearly defined, while the surrounding or peripheral cells are flattened, larger, and in more intimate contact with the yolk beneath.

BLASTULATION

The chick embryo remains in the morula stage for a very short period, when there is a rearrangement of cells preliminary to the blastula formation. First, a cavity forms beneath the blastoderm due to the smaller central cells separating from the underlying yolk. The outlying cells remain attached. This space is called the **segmentation cavity** or **blastocoel,** while the marginal area of the blastoderm which remains attached to the yolk is called the **zone of junction.** As soon as the segmentation cavity is thus formed the embryo is said to be in the blastula stage.

From Figure 259, which shows only the blastoderm and a portion of the yolk (the yolk being about three feet in diameter at this magnification), a good understanding of the difference a larger amount of yolk makes in the blastula-formation may be had.

In eggs with little yolk a definite morula or solid sphere of cells can easily form, which may then develop into a hollow sphere or **blastula.** But in eggs with a large quantity of yolk, as in the pigeon and the chick (Fig. 258), the blastomeres are forced to grow on the surface of the

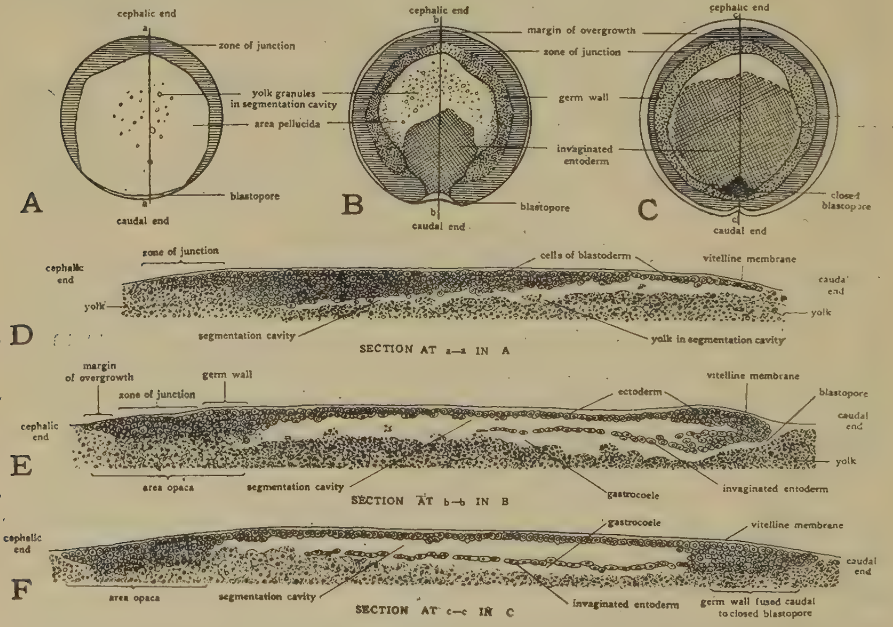


Fig. 259.

Diagrams to show various stages in the gastrulation of a bird embryo. In the surface-view plans, the blastoderm is supposed to be transparent so the underlying structures may be located. A, surface view of blastoderm, just before invagination; *B*, surface view of blastoderm, invagination well advanced; *C*, surface view of blastoderm at end of gastrulation; *D*, vertical section through blastoderm of stage represented in *A;* The plane of section is indicated by the line *a-a* in *A*. *E*, vertical section through blastoderm of stage represented in *B*. The plane of the section is indicated by the line *b-b* in *B*. *F*, vertical section through blastoderm of stage represented in *C*. The plane of the section is indicated by the lines *c-c* in *C*. (From Patten, after Patterson's figures for the pigeon.)

yolk, which is the mechanical reason for the disc-shaped blastoderm being where it is and what it is in the bird's egg. That is, if the large yolk of a bird's egg were removed and the blastoderm were allowed to assume the spherical shape it would naturally take due to surface tension, there would be a decided similarity between the disc-shaped blastoderm and the ordinary morula stage of eggs with little yolk, such as in amphioxus and in man.

Not only does the great quantity of yolk make this change in the morula stage, but it is evident that a large amount of yolk does not permit a simple hollow sphere formation by any method of cell arrangement. Nevertheless, the central cells do separate somewhat from the yolk and form the slight segmentation cavity mentioned above.

Imagining, now, that the yolk could be removed and the ends of the blastoderm drawn together, we should have a true blastula form of the simpler type.

GASTRULATION

It is essential that one remember that a large quantity of yolk will make a considerable change in the process of gastrulation. The simpler

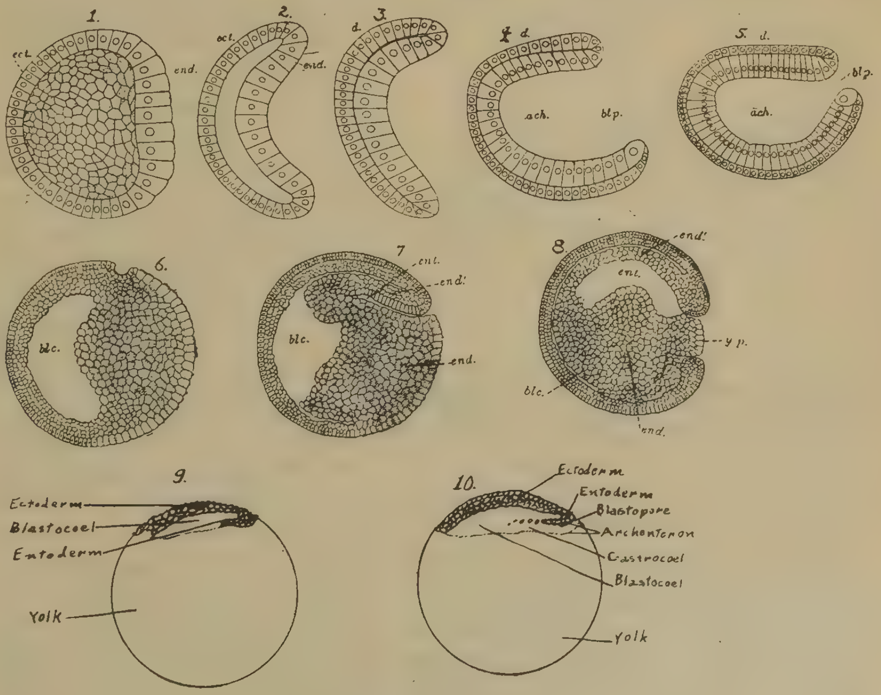


Fig. 260.

Gastrulation in egg with different quantities of yolk. 1-5, Amphioxus (little yolk); 6-8 Amphibian (moderate amount of yolk); 9-10, Birds (large amount of yolk); *blc*, blastocoele; future dorsal side; *ect.*, ectoderm; *end.*, entoderm; *ent.* and *ach.*, archenteron; *blp.*, blastopore; *y.p.*, yolk plug. (After various authors.)

forms are brought about by an inpushing of the outer layer of the blastula as one indents a rubber ball. This forms a two walled (ectodermal and entodermal) cup with a cavity in the center called a **gastrocoele.** The opening itself is known as the **blastopore** (Fig. 260).

In birds with a large amount of yolk, the blastula cannot indent completely into the blastocoele, due to the disc-shaped blastoderm not being a true hollow sphere. The very small blastocoele formed between the blastoderm and the yolk, allows but little infolding. The blastopore in the case of an indented sphere is relatively large. In the chick there is but a tiny blastocoele, while the blastopore is but a small crescent-shaped slit at the margin of the blastoderm (Fig. 251, C). This slit is to be thought of, however, as similar to the regular round opening in simpler forms, which has been pushed together by the yolk not yielding. The infolding entoderm is also naturally compressed and flattened by the tiny blastocoele into which it can grow. In fact, the lower layer of the infolding entoderm seems to be prevented from growing normally by the unyielding yolk, and so is broken and lies on the yolk as scattered cells. These scattered cells then shortly disappear so that the yolk itself forms the floor of the gastrocoele.

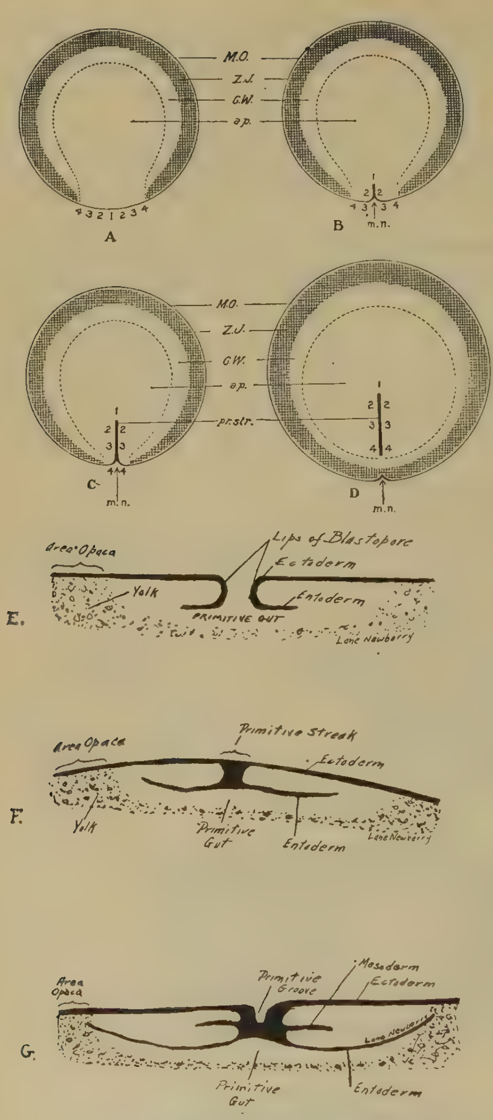


Fig. 261.

A to *D*. Diagrams illustrating the idea of confluence (concrescence) as applied to the chick. The central area bounded by the broken line represents the area pellucida; external to this is the area opaca, showing the germ wall (*G. W.*), zone of junction (*Z.J.*), and margin of overgrowth (*M.O.*). *m.n.*, Marginal notch.

E to *G*, Diagrammatic relations of the germ layers at the time the primitive streak is formed by concrescence of the blastoporal margins. *E*, section of stage *B*; *F*, section of stage *D*; *G*, section through blastoderm of a 16 hour chick embryo. (*A* to *D* from Lillie's "The Development of the Chick," by permission of Henry Holt & Co.)

Figure 260 presents a diagrammatic scheme which makes it possible to see the general outlines of gastrulation in eggs with varying quantities of yolk.

The zone of junction, where the peripheral region of the blastoderm remains attached to the yolk, is called the **area opaca,** because when the blastoderm is removed from the yolk-surface for laboratory study, the yolk is so closely attached to this region that it adheres to the blastoderm and renders the area more opaque. The more central portion which thus has no yolk attached, is more translucent and is therefore called the **area pellucida.**

The area opaca later differentiates into the following three more or less distinct zones (Fig. 261):

(1) The **margin of overgrowth:** Being a peripheral zone where rapid proliferation pushes the cells out over the yolk without their adhering to it.

(2) The **zone of junction:** Which has an intermediate zone in which the deeper lying cells have no complete cell boundaries, so that they form a syncytium which blends (without a definite boundary) with the superficial layer of white yolk to which it adheres by many penetrating strands of cytoplasm.

(3) The **germ wall:** Being an inner zone made up of cells derived from the inner border of the zone of junction, which have acquired definite boundaries and become more or less free from the yolk. Numerous small yolk granules are usually found in the germ wall, due to the fact that these were contained in the cytoplasm when they were still connected with the yolk as cells of the zone of junction. It is the inner margin of the germ wall which separates the area opaca from the area pellucida.

When the chick embryo is ready for gastrulation, there is a thinning of the blastoderm at the caudal margin with a consequent freeing of the blastoderm at the caudal margin from the yolk (Fig. 259, D). In a surface view, the crescent shaped gap in the posterior quadrant of the zone of junction marks the separation of the blastoderm from the yolk (Fig. 259, A). The blastopore is that region where the blastoderm is free from yolk and where it is likewise very thin.

It will be remembered that cell proliferation is continuous throughout the entire blastoderm. The surface extent has now become much greater by a general spreading out of the peripheral margins over the yolk, but this extension, while taking place uniformly at the margins, varies at the blastopore. This being at the posterior free end of the blastoderm, the cells, as they proliferate, grow inward to form the entoderm. Once this differentiation has taken place, the part of the margin forming this entodermal portion takes no further part in the peripheral expansion, though this entodermal part grows back toward the center of the blastoderm, leaving the blastopore region behind. The marginal region continues to grow and soon encloses it, so that by the time the blastopore comes to close, it lies within the recompleted circle of the germ wall (Fig. 259, C).

CHAPTER XXX.

THE PRIMITIVE STREAK AND ORIGIN OF THE MESODERM

All that has been described so far has actually taken place before the egg is laid. The real beginnings of a distinguishable embryonic area may be said to start with the **primitive streak.** While there are various theories as to just how this thickened streak is formed, the most logical and intelligible is that it is a thickening formed by the two lips of the blastopore meeting and growing downward.

To make this clear, the student will remember that throughout this entire volume, the blastula has been considered a hollow sphere composed of a single layer of cells, and the gastrula was this same hollow sphere after it had indented so as to form two layers. The opening where the indentation took place was called the blastopore.

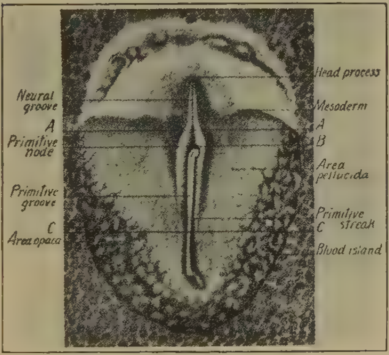


Fig 262.

Dorsal view of 16 to 20 hour chick embryo showing primitive streak, primitive groove, primitive node, beginning of neural groove, blood-islands, and extent of mesoderm. (After Duval.)

In the chick-embryo we are to think of this blastula, however, not as a sphere, but as sausage-shaped, with the indentation taking place from about the center of the long axis to one end. Thus we do not have a round blastopore, but an **elongated one.** And it is the closing of the lips along this elongated slit which forms the thickening called the primitive streak (Fig. 262). It is clearly seen at sixteen hours of incubation, not only as a thickening, but as an indentation—the **primitive groove**—with ridge-like thickenings flanking each side, and extending from the area opaca to almost the center of the blastoderm. The part lying closest to the area opaca is the caudal end, and the direction of the streak forms the long axis of the embryo. At the cephalic end of the primitive groove there is a deepening called the **primitive pit,** and directly anterior to this the two lips of the primitive folds meet in the midline to form a small rounded elevation known as **Hensen's node.** This node serves as the region of demarcation separating the fast disappearing primitive streak from the notochord, which forms cephalad to it in the long axis of the embryonic area. The growth of the embryo is much greater headward than caudally or laterally, so that the antero-posterior axis becomes considerably elongated.

The lips of the blastopore form a region of rapid cell proliferation, though all the cells look quite alike. Nevertheless, it is from these rapidly proliferating cells that the various germ layers are derived.

Figure 263 shows an enlarged longitudinal, as well as a cross section of an early embryo. As the lips of the blastopore grow closer and closer together, they finally fuse, forming the primitive streak. Ectoderm and entoderm cannot be distinguished, but from the thickened approximation of the lips of the blastopore there is an inward growth of a single layer of cells now called entoderm, and from between these two layers some rather loosely arranged cells form a third layer, considered the primitive origin of what is later to be called **mesoderm.**

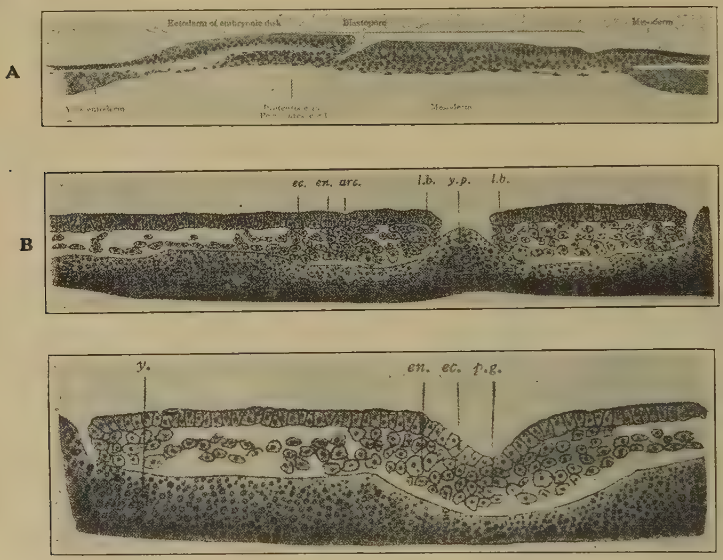


Fig. 263.

A. From medial longitudinal section through embryonic disk of Chick. *Bonnet.*

B. From transverse section through Hensen's node—germ disk of chick of 2 to 6 hours' incubation. *Duval.* For lettering see Fig. C.

C. From transverse section through primitive groove—germ disk of chick of 2 to 6 hours' incubation. *Duval.* *arc.*, Archenteron; *ec.*, ectoderm; *en.*, entoderm; *l.b.*, lip of blastopore; *p.g.*, primitive groove; *y.*, yolk; *y.p.*, yolk plug.

At the same time this mesodermal outgrowth appears, the dipping down of the outer layer occurs, forming the **primitive groove.**

The three layers which have thus been established are very important, because in all forms of animal life so far studied, there is a decided similarity in the origins and developments of the various organ systems. Therefore, an understanding of the way the germ-layers and the organ systems arise, alone permits an understanding of the ever increasing perplexities coming forth as these in turn develop further.

In our study of comparative anatomy we shall see why it is that all outer coverings of the body as well as the nervous system are derived from the ectoderm; why the lining of both digestive and respiratory organs comes from the entoderm; and why the circulatory system as well as the blood, lymph, muscle and connective tissue (except neuroglia) are derived from the mesoderm.

The primitive streak, relatively, seems to become pushed further and further tailward, but this is due to the greater growth in the cephalic region of the embryo. (Compare Figures 262 and 264.)

The entoderm spreads out as a very definite layer of cells, and merges peripherally with the inner margin of the germ wall, even overlapping it slightly. The little cavity between the yolk and this entodermal layer which has been called the gastrocoele will henceforth be known as the **archenteron** or **primitive gut** (Fig. 265). The student is not to look for a cavity in his sections, however, as the yolk in this region, by the very fact that it is separated from the entoderm and forms the floor of the primitive gut cavity, will not adhere to the embryo when it is removed for sectioning purposes.

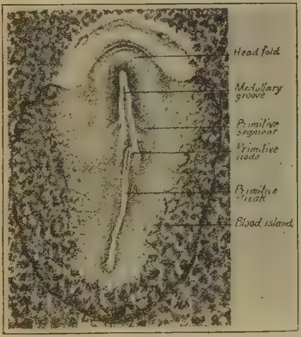


Fig. 264.

Surface view of a twenty-one hour chick embryo, in which the head-fold and first pair of primitive mesodermal segments are present. (After Duval.)

At eighteen hours of incubation the cell boundaries of the germ wall cannot usually be seen, though there are many nuclei and yolk granules, the latter in various stages of absorption. Because the nuclei of the germ wall arise by division of the nuclei of the cells lying at the margins of the expanding blastoderm, it is assumed they are instrumental in breaking up the yolk in advance of the arrival of the spreading entoderm about the yolk sphere.

At about twenty-two to twenty-three hours of incubation a pocket of entoderm can be seen in the anterior region by examining the whole mount, and focusing through the ectoderm. This is the first formation of a gut floor in addition to the yolk which has been answering that purpose up to this moment. This pocket forms the **fore-gut.**

The mesoderm grows laterad and then extends cephalad, so that an area between the two cephalad growing portions of mesoderm is formed, which area is called the **proamnion** (Fig. 266, P). It is merely an open space and must not be thought of as forming the later true amnion. It is to be noted primarily, because it permits a better study of just how the mesoderm grows in relation to it. It will be well to observe the difference in this space in eighteen and twenty-three hour embryos.

As the mesoderm begins its growth where it does, there is none of it in the midline except posterior to the primitive streak; but, immediately on each side of the midline, the mesoderm is quite thickened, thinning out as it extends toward each side. The dorsal mesodermic plates are to develop from these thickened portions of the mesoderm, and as they will then segment, they are called **segmental zones** of mesoderm. The first somites will appear cephalad to Hensen's node, extending caudally along each side of the primitive streak and becoming less and less distinct.

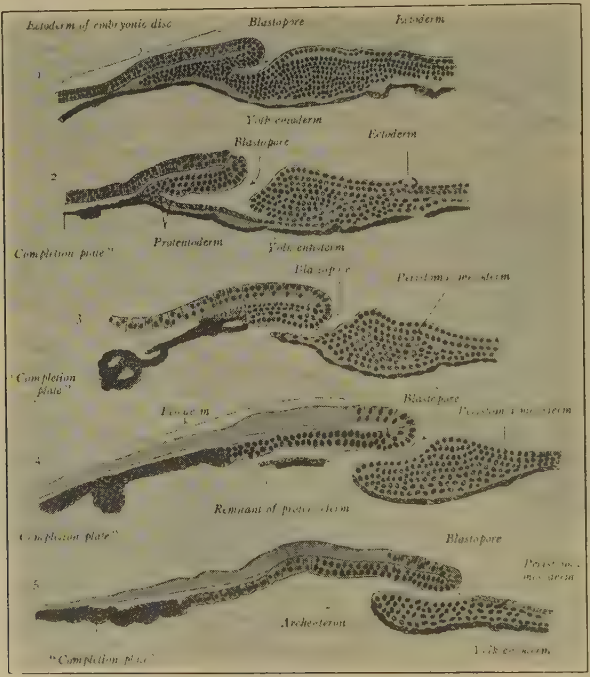


Fig. 265.

From medial vertical sections through embryonic disk of lizard, showing five successive stages in gastrulation (Wenckeback, Bonnet).

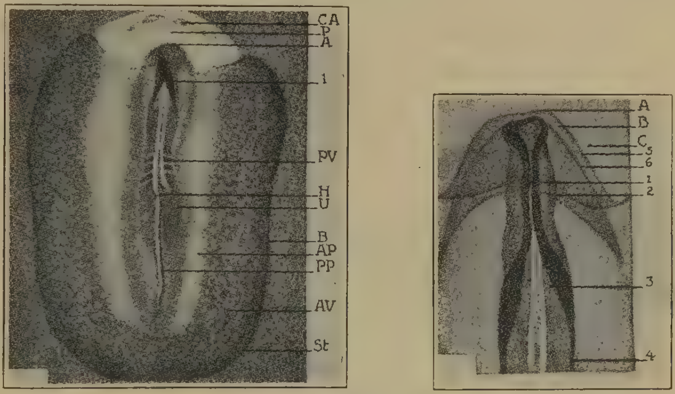
It is important to note here that the sheet-like layers of mesoderm so characteristic in the mid-body region do not extend to the head region of the embryo. The mesoderm of the head region develops from quite definitely organized layers immediately behind the future head. The reason that the mesoderm of the head is separate in origin from that of the remaining portion of the body may be accounted for by the fact that the head is not segmented as is the mesoderm of the body-region.

THE NOTOCHORD

From the cephalic end of the primitive streak the rapidly proliferating cells extend in an anterior manner. In non-bird-like vertebrates, the notochord extends from the region of the anterior lip of the blastopore, so it is assumed that this is also the case in birds.

If the student will think of assumptions and incidents of this kind, and note the manner in which hundreds of such assumptions and incidents must be gathered from all angles and from hundreds of experiments by hundreds of different investigators, to make such a study as embryology possible, he will obtain at least some slight appreciation of what **scientific investigation** means and what **scientific method** means.

In reading the literature of the subject, the student will note that probably most writers insist that the notochord develops from the entoderm, though there are those who believe it comes from either of the other two layers, and some even that it comes from all three.



A Fig. 266. **B**

A.—Surface view of Embryo at the Twenty-third Hour of Incubation. *A.*, anterior limit of head; *AP.*, area pellucida; *AV.*, area vasculosa; *B.*, border of mesoderm; *C.A.*, yolk crescent; *H.*, Hensen's node; *P.*, proamnion; *PP.*, primitive streak; *PV.*, mesoblastic somites; *St.*, sinus terminalis bounding the vascular area; *U.*, unsegmented mesoderm. *l*, region where the medullary folds have almost met to form the medullary canal.

B.—Anterior part of the preceding figure more highly magnified to show details. *A*, ectoderm of anterior end of head; *B*, mesenchyme; *C*, subcephalic pocket: 1, region where the medullary folds will begin fusing to form medullary canal; 2, margin of the anterior intestinal portal; 3 and 4, posterior regions of medullary folds; 5, lateral limits of head region; 6, border of foregut. (From Duval.)

In all forms studied, however, the notochord is not seen to arise from any definite layer, but it arises either at the **same time the mesoderm does** (Fig. 267), or from the **undifferentiated growth of cells about the closed blastopore** which gives rise to both entoderm and mesoderm.

The notochord itself is a rod-shaped structure, circular in cross section, extending headward from Hensen's node.

THE NEURAL PLATE

A thickening of the ectoderm at about eighteen hours' incubation causes a greater density along each side of the notochord. This denser area is several cells in thickness, and forms what is called **the neural or**

medullary plate. The cephalic ends of these plates seem to bend; but from Hensen's node caudad, they diverge into thickenings on each side of the primitive streak.

At twenty-one to twenty-two hours the outer portions of the neural plate bend dorsally toward the midline and form the **neural** or **medullary groove,** the ridges thus formed being called the **neural** or **medullary folds** (Fig. 266, B). This is the first differentiation of the nervous system.

After this period of incubation the denser portion which has formed by all the cell differentiation mentioned above, is called the **embryonal area,** and the outer peripheral region of the blastoderm is called the **extra-embryonic area,** because from this extra-embryonic region arise those structures which are not part and parcel of the embryo itself, but serve as protective and nutritive layers.

At this period the **anlage** of the head appears as a rounded elevation with a definite crescent-shaped head-fold, the first definite boundary of the growing embryo.

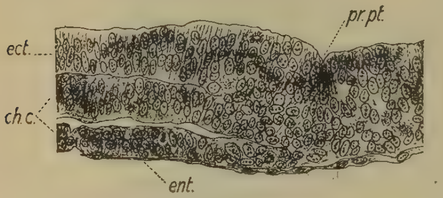


Fig. 267.

Sagittal section through region of primitive node and caudal end of chordal canal of guinea pig (13½ days after fertilization) to show beginning of notochordal cells and ectodermal cells in one layer. *Ect.*, ectoderm; *ent.*, entoderm; *ch.c.*, chordal canal, dorsal and ventral wall closing lumen; *pr.pt.*, primitive pit. (After Huber in The Anatomical Record, April 20, 1918.)

It is well at this point to know what is to become of the mesoderm, so that we may have several landmarks which will stand us in good stead.

In the earthworm, it will be recalled, the entire animal is segmented, that is, composed of **metameres,** while in the frog, segmentation shows itself primarily in the spinal column.

In both earthworm and frog the segments are composed of an outer layer of ectoderm, an inner layer of entoderm, and a middle layer of mesoderm.

When one speaks of metameres, one always means segments lying **one behind the other,** but now we must think of a sort of segmentation also in each metamere, one below the other (Fig. 268). In fact, this we must do if we are to understand that which follows.

Figure 268 shows a combination transverse and longitudinal arrangement of metameres with the mesoderm divided into an outer (somatopleure) and an inner (splanchnopleure) layer, and the segments also divided horizontally.

The more dorsal portion of the horizontal divisions is called an **epimere,** the mid-portion a **mesomere** (which is the beginning of the excretory system), and the more ventral portion is known as a **hypomere.** The whole metamere is called a **mesomeric somite.**

In vertebrates, as we have seen, segmentation is observable primarily in the region of the spinal column. Therefore, in the study of vertebrates, such as the chick, we shall find that, while segmentation begins along the future spinal region, only the more dorsal portion of the mesoderm is segmented, and that only partially. The epimeres alone, that is, the paired parts lying at the side of the notochord, are truly segmented, though the opening in them, the **epicoele,** shortly disappears. The mesomeres with their mesocoeles develop into the excretory system, and the hypomeres, which have not segmented, but whose opening, the **hypocoele,** is continuous throughout the entire region where there has been any segmentation, is now to be known as the **coelom** or **body cavity,** into which the internal organs are to grow.

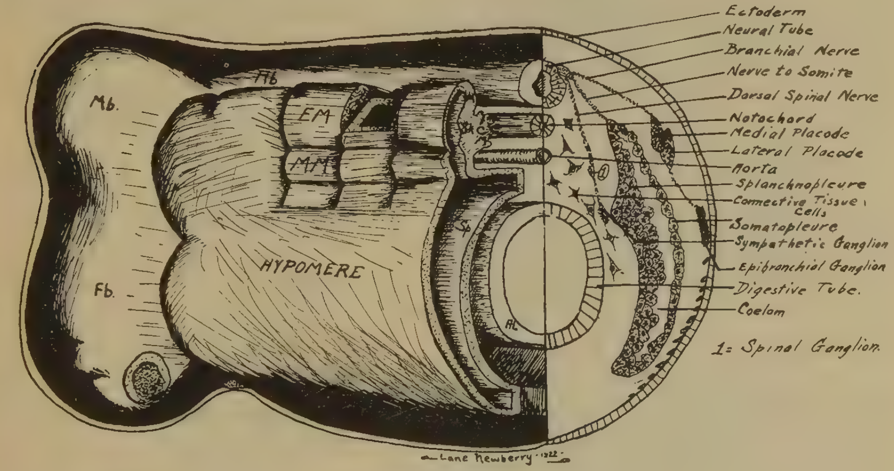


Fig. 268.

Stereogram showing the segmentation of the mesothelium. The dorsal and ventral walls of the coelom later fuse to form the dorsal and ventral mesenteries. *Al,* alimentary canal; *EM,* epimere; *Fb,* forebrain; *Hb,* hindbrain; *M,* (under *Sk.c.*), myotome; *Mb,* midbrain; *MM,* mesomere; *sk.c.,* sclerotome. *Sp,* splanchnic layer of the mesoderm (splanchnopleure). (Modified from Kingsley.)

It is to be remembered that epimere, mesomere, and hypomere are composed of mesoderm only.

As the mesoderm begins to grow laterad and ventrad, and while it is yet unsplit into an outer and inner layer, the thickened portion lying on each side of the neural groove is called the **vertebral plate,** and the more distal portion, the **lateral plate.**

The outer layer of the lateral plate, after it splits into two sheets, is called **somatic mesoderm** (and after connecting with the ectoderm the **somatopleure)** while the inner layer, the **splanchnic mesoderm,** connects with the entoderm and is known as the **splanchnopleure** (Fig. 268).

In the head region, the cells of the vertebral plate scatter and combine with cells which are continually being budded off from the walls of the fore-gut to form the **mesenchyme** of the head region (Fig. 269). It will thus be seen that mesenchyme is made up of a combination of cells from both mesoderm and entoderm, and even of ectoderm, for, scattered cells later join from the ectoderm of the head region.

The somites begin forming in the region of the more anterior end of the primitive streak, the first one to develop remaining the more anterior. The first four pair of somites take part in the development of the hinder part of the head region of the embryo.

A further important factor to remember at this point is that segmentation is fundamental, and that consequently any structures in the body which show segmentation, only follow out some plan of the original segmentation. This is of value in tracing the growth of various body-parts, such as muscles, for instance, in that the nerve supply, which we shall shortly see is also of segmental origin, definitely tells us where a muscle springs from, because nerves always follow muscles, and not vice versa.

The **somatopleure, splanchnopleure, and coelom** become separated into **embryonic** and **extra-embryonic regions** later, although at this early stage of which we are writing they form continuous structures which extend laterally out from the germ wall, and anteriorly into the head region.

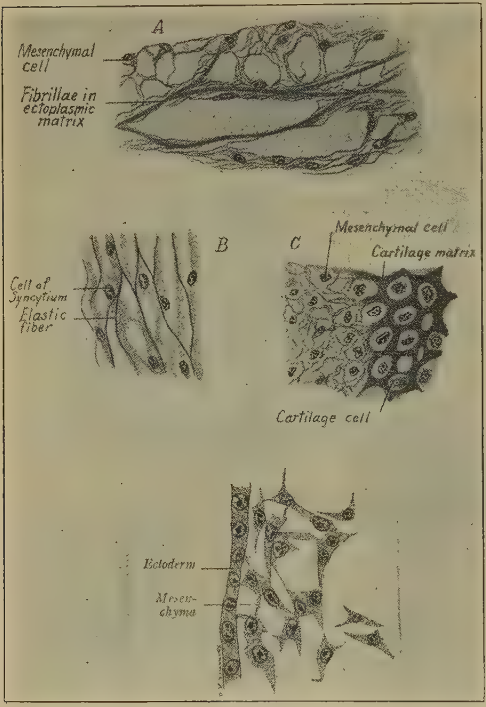


Fig. 269.

Figures showing the differentiation of the supporting tissues (after Mall). *A*, white fibers forming in the dermis of a 5 cm. pig embryo; *B*, elastic fibers forming in the syncytium of the umbilical cord from a 7 cm. embryo; *C*, developing cartilage from the occipital bone of a 20 mm. pig embryo. Mesenchyma from the head of a thirty-six hour chick embryo.

The following structures are developed from the embryonic portion:

body-wall,
gut-wall,
vascular organs,
pericardial cavity,
pleural cavity,
peritoneal cavity.

From the extra-embryonic portion the following are developed:

- embryonic membranes and appendages,
- extra-embryonic portions of the vascular system,
- extra-embryonic coelom (exocoelom).

Probably the most understandable method of making much of what has been said clear, is to use Professor Reese's method of illustration:

"An understanding of the way in which the embryo becomes folded off from the rest of the egg, may perhaps be obtained in the following way: Cut out four circles of cloth, say 75 cm. in diameter, of three different colors. Put the two circles that are of the same color together and then put these two circles between the other two.

"Let these superimposed circles represent a greatly enlarged blastoderm that has been removed from the yolk to which it was originally attached. The upper layer of cloth will represent the ectoblast, the bottom layer will represent the entoblast, and the two similarly colored layers in the middle will represent the two layers of the mesoblast after their separation.

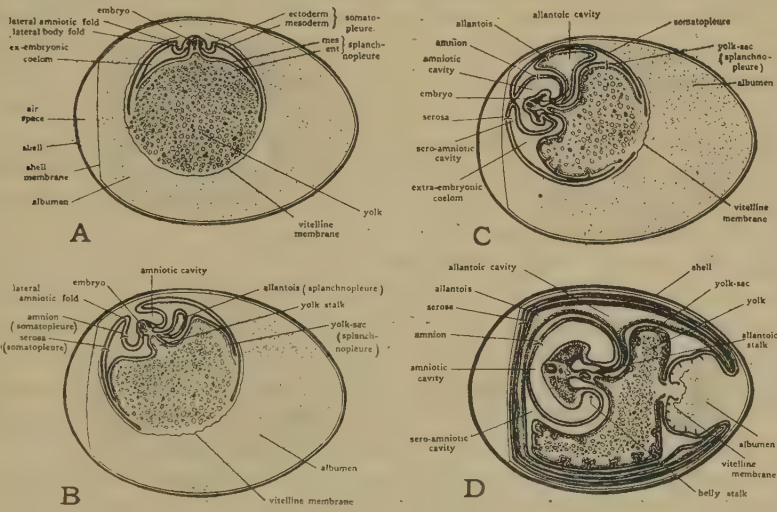


Fig. 270.

Schematic diagrams showing the extra-embryonic membranes of the chick. The egg is cut longitudinally while the embryo (which lies at almost right angles to the egg), is cut transversely. *A*, embryo at about 48 hours; *B*, same at about 72 hours; *C*, same at about five days; *D*, same at about fourteen days. (After Duval.)

"As the yolk takes no actual part in the formation of the embryo other than as a supply of the food for the growth of the constantly enlarging chick, it may be omitted from our model.

"Now spread the cloth-blastoderm upon a table and place under its centers a small object, such as a bottle. If now, the fingers of one hand be pushed under one end of the bottle, carrying, of course, the three germ layers with them, we shall have represented the formation of the head fold. By pushing under the cloth at the other end of the bottle, in the same way, we may represent the formation of the tail fold; and in a like manner the lateral folds may be formed. If these folds, the head, tail, and lateral be pushed under far enough, they will meet under the center of the bottle, and we shall have the bottle, with its surrounding layers of cloth, connected with the rest of the model by only a sort of stalk, which is hollow and composed of the three layers of cloth. The bottle is used simply to give a solid object around which the folding may be more easily done, but we are to consider the space occupied by the bottle as an **empty** space.

"We have now represented what is sometimes called the **embryo-sac**, or simply the embryo, in contradistinction to the yolk-sac, or simply the yolk. The embryo remains connected with the yolk throughout the period of incubation by the **yolk-** or **somatic**-stalk, and as the embryo increases in size, the yolk-sac is, by absorption, constantly diminished. The space occupied by the bottle, in our model, represents the digestive tract of the chick, and is lined, as will be seen by examination of the model, by the lower germ layer, or entoblast. The body cavity would be difficult to represent in the cloth model, but it can be imagined to exist as the narrow space between the two layers of similarly colored cloth which we have just called the mesoblast.

"The formation of the amnion may be represented in our model by lifting up with the fingers a small fold of the upper and second layers of cloth, and pulling these two layers back over the head end of the embryo, this fold will correspond to the head fold of the amnion. Similar folds might be lifted up at the posterior end and at the sides of the embryo model, to represent the tail and lateral folds of the amnion. The way in which these folds fuse together will be explained later."

The allantois cannot be explained from the model, but can be understood by studying Figure 270. It arises as a thin-walled pouch from the posterior end of the digestive tract, and as it increases in size, it extends around the upper side of the embryo, between the inner and outer layers of the amnion.

Both amnion and allantois are thrown off at hatching, so take no permanent part in the actual embryo.

CHAPTER XXXI.

THE FOUR TO SIX SOMITE STAGE

(About Twenty-four Hours)

As the embryo is already well on its way in development at the time the egg is laid, and as it has been shown that the extent of development varies considerably on account of the retention of the egg in the hen for an extra twelve to sixteen hours if it is not ready for laying sufficiently early in the day, the formation of the block-like portions of mesoderm—the somites—becomes the more accurate measurement of the age of an embryo. Chicks with the same number of somites do not usually vary much among themselves in general, though individual parts often do; while chicks having been incubated for the same number of hours vary considerably in all parts.

The twenty-four hour stage (four to six somites), (compare Figs. 264 and 266), is of great importance, for it is during this very early period of the chick's life that the interesting and important differentiating processes are noted. Up to the time the first four somites form the hind-brain, the entire growth of the embryo from Hensen's node cephalad, has been a formation of the head-region only.

There has been some question in the past as to whether or not additional somites are formed anterior to the first ones thus laid down. Patterson performed an interesting experiment which seems to warrant our saying that such is not the case.

Professor Patterson incubated six eggs up to the one somite formation period, and then with the most asceptic precautions, opened the eggs and marked the first somite by injuring it with an electric needle, or inserted a minute glass pin therein. The shell was then again closed by a small piece of egg-shell, and the eggs again incubated for varying number of hours before being reopened. No new somites appeared anterior to the injured one.

In the study of whole mounts under the microscope, it must be remembered that reflected light coming up from below the object shows different densities as darker or lighter areas. Any portions of the embryo which have become thickened or folded over will therefore appear extremely dark and be thus distinguished from the thinner and lighter areas.

At the end of about twenty-four hours we then have:

1. Three definite germ layers. (Fig. 271.)
2. Four to five somites, forming in the vertebral plates, which vertebral plates have separated from the lateral plates.
3. The mesoderm divided into a somatic and a splanchnic layer.

4. The neural groove almost but not quite closed.
5. A clearly outlined fore-gut and mid-gut.
6. Clearly defined head-folds marking the anterior limit of the embryo.
7. A definite notochord extending from the anterior end of the primitive streak to what is to become the mid-brain.
8. The pellucid area is more or less pear-shaped and the vascular area is seen as an inner zone of the area opaca.
9. The primitive streak is rapidly becoming relatively shorter and is soon to disappear, the cells of which it is composed probably becoming rearranged to form other structures.

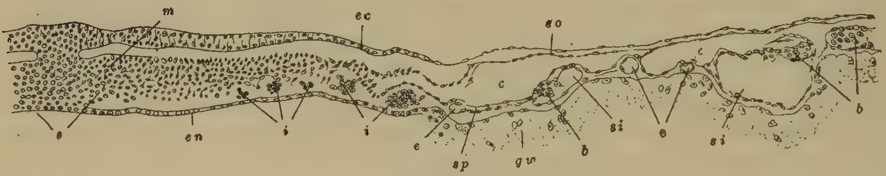


Fig. 271.

Transverse section through the primitive streak of a chick with six pairs of mesodermal somites (about twenty-four hours), showing the formation of the blood-vessels and blood. The section extends from the mid-line, nearly half across the area vasculosa. *b*, Blood cells; *c*, cœlomic spaces; *e*, empty endothelial tubes; *ec*, ectoderm; *en*, endoderm; *gw*, germ wall; *i*, solid blood island; *m*, axial mesoderm; *s*, primitive streak; *si*, vascular sinuses of area vasculosa; *so*, somatic mesoderm; *sp*, splanchnic mesoderm. (After Rückert.)

From the twenty-fourth hour on, the texture of the embryo becomes firmer, and, whereas, it is difficult to remove an eighteen-hour embryo without tearing, the twenty-four hour embryo can easily be removed. All outlines become clearer now also.

The anterior part of the embryonal area has thickened, and is slightly lifted above the remaining blastoderm as shown by the crescent-shaped anterior boundary (Fig. 266, B). The embryo grows forward over this crescent-shaped fold which thus comes to lie under the embryo and forms a little pocket between the embryo and the fold called the **subcephalic pocket.**

The neural folds now unite in the region of the future mid-brain, closing rapidly posteriorly, and slowly anteriorly. The closed portion is called the **neural tube**. The most anterior portion where the neural tube will close is known as the **neuropore,** which is the region of what is later to become the **lamina terminalis.** This lamina terminalis is usually regarded as the **morphologically anterior limit** of the brain. **Topographically,** however, **this is not the case,** for the fore-brain grows forward and then bends back downward in front of the fore-gut, the whole thing becoming bent like a shepherd's crook, so that the morphologically anterior end comes to lie on its antero-ventral aspect.

The neural folds have a somewhat flattened crest, and these fold inward, forming a vertical contact. The neural tube is thus formed by the fusion of the lower or inner margins of these surfaces, the upper ones again forming a continuous ectoderm, so that the neural tube becomes entirely separated from it. The cells lying between this ectodermal and lower margin, and which have been derived approximately from the apices of the neural ridges, become the **neural crests** (Fig. 272). These crests do not fuse in the midline, but remain as a pair of longitudinal bands along the dorsal-lateral surfaces of the neural tube, and are the rudiments of the **ganglia of the cranial and spinal nerves.** They are not uniformly developed, and appear much clearer in some sections than in others.

Already very early in the area opaca considerable modification has been going on. The area itself has broadened and in both lateral and posterior regions it is mottled. This mottled portion is due to the forming of differentiated cell groups forming what are called **blood-islands** (Figs. 262, 264), which are the beginning of the vascular system. The portion of the area opaca in which these blood-islands occur is known as the **area vasculosa.** This area vasculosa begins immediately behind the embryo, but then extends laterally and anteriorly, while around its periphery a single definite blood vessel forms, known as the **sinus terminalis** (Fig. 284, C). Beyond this sinus terminalis, all the remaining area opaca consists of ectoderm and entoderm, and extends around the yolk. It is then called the **area vitellina.**

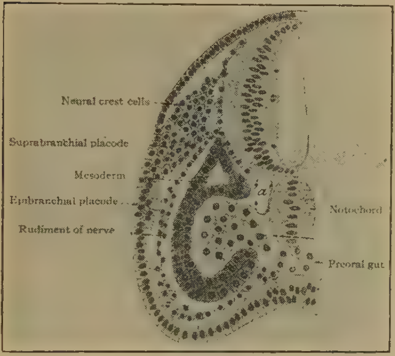


Fig. 272.
Transverse section through the head of a 7 day Ammocœtes in the region of the trigeminal ganglion. *von Kupffer.*

The compact cell masses forming these blood-islands have been formed throughout the deeper portion of the germ wall, becoming covered superficially with a deep layer of scattered germ wall cells. This superficial layer comes to be known as **coelomic "mesoderm."**

This superficial layer and the blood islands become continuous very early with the mesoderm of the pellucid area derived from the primitive streak (Fig. 273). The blood islands become hollowed out, forming **lacunae.** The cells which have formed the blood islands become both the blood-vessel walls and the blood cells. The lacunae then anastomose, forming a complete network extending to meet the vascular structure of the pellucid area and later of the embryo.

The cellular portion of the germ wall which remains after the coelomic "mesoderm" and the blood islands have differentiated, forms the rudiment of the yolk-sac entoderm, to be described later.

As soon as the extra-embryonic coelom forms, dividing the mesoderm into somatic and splanchnic layers, the blood vessels remain associated with the splanchnic layer.

Just as the somites are beginning to form, blood vessels will be found at the margin of the pellucid area beginning to grow toward the embryo. Only the tubular vessels develop in the area pellucida; the blood islands, as already noted, develop in the area opaca. This means that the cellular or **corpuscular elements** of the blood arise in the posterior region of the area opaca.

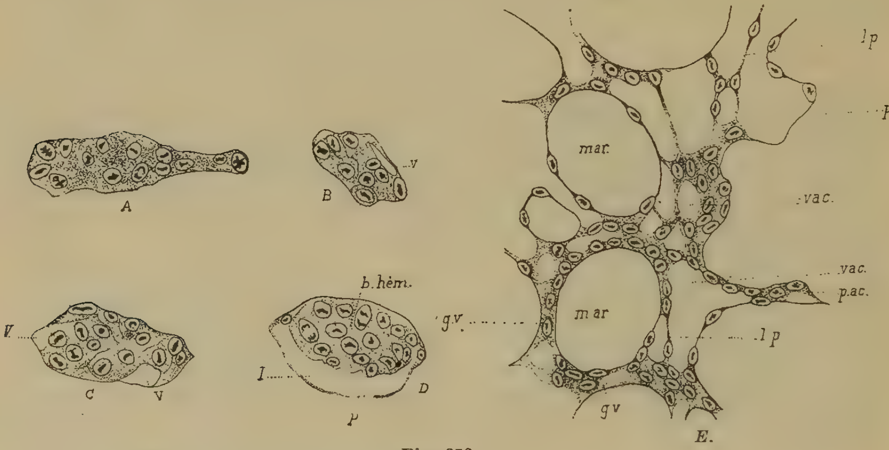


Fig. 273.

Beginning of the vascular system in the chick embryo. *A*, complete blood-island; *B* and *C*, beginning of vacuole formation; *D*, vacuoles becoming confluent to form the lumen of the blood vessel. *b.hem.*, primitive red blood cells; *l*, lumen; *p*, vessel-wall; *v*, vacuole or lacunae. (After Uskow). *E*. A portion of the vascular network destined to become the aorta in the chick embryo. *gv*, primitive blood forming cells; *lp*, cytoplasmic lamina persisting in the lumen of the blood vessel that has formed; *mar*, blood vessels; *p*, vessel wall; *p.ac.*, point of enlargement of network; *vac*, vacuoles. (From Vialleton.)

Professor Rückert has worked out the arrangement of the blood vessels (Fig. 284). He says the vessels in the area pellucida are formed by a rearrangement of small groups of cells in the splanchnic mesoderm of the area. First, short sections of tubular vessels are formed, which then connect with the more peripheral vessels of the opaque area, thus forming a continuous vascular network extending toward the embryo and finally reaching it at about the time six pairs of somites are formed.

Soon after this, vessels appear in the embryo itself, the first being the paired **dorsal aortae** in the body region. These are regarded as merely straightened axial margins of the vascular network of the area pellucida. They diverge widely posteriorly, passing as the **vitelline arteries** into the general vascular network. Anteriorly they are prolonged forward to the heart region where they connect with a pair of vessels differentiated in the mesenchyme of the head.

It will be remembered that the coelom is really paired, and extends downward ventrally on both sides until at a later period it meets in the ventral midline and fuses to form the one cavity which it later becomes in all vertebrates. The crescent-shaped line where fore-gut and mid-gut meet is called the **anterior intestinal portal** (Fig. 266, B).

It is in the region of the anterior intestinal portal that the coelomic chambers on both sides show a marked enlargement. The enlargement of each side extends mesiad toward the other, and finally both break through into each other ventral to the fore-gut, to form the pericardial cavity. These enlarged regions are called the **amnio-cardiac vesicles** (Fig. 274) in their early stages; however, it is better to remember what they are to become, and think of them as the **pericardial region of the coelom.**

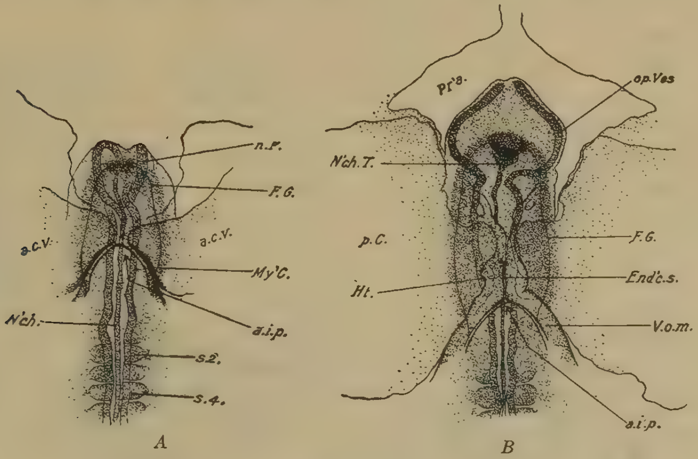


Fig. 274.

Ventral views of the head ends of chick embryos. *A.* Embryo with five pairs of somites (about twenty-three hours). *B.* Embryo with seven pairs of somites (about twenty-five hours). *a.c.v.*, Amnio-cardiac vesicle; *a. i. p.*, anterior intestinal portal; *End'c.s.*, endocardinal septum; *FG.*, fore-gut; *Ht.*, heart; *My'C.*, myocardium; *N'ch.*, notochord; *N'ch.T.*, anterior tip of notochord; *n.F.*, neural fold, *op. Ves.*, optic vesicle; *p.C.*, parietal cavity (cœlomic); *Pr'a.*, proamnion; *s.2*, *s.4*, second and fourth mesodermal somites; *V.o.m.*, omphalo-mesenteric vein. (From Lillie's "Development of the Chick" by permission of Henry Holt & Co., Publishers.)

The splanchnic mesoderm is thickened at the point where it lies closely applied to the entoderm at the lateral margins of the portal. It is from these thickened areas that the paired primordia of the heart will arise later.

It will thus be noted that the heart develops from the ventral and not the dorsal aspect.

The amnio-cardiac vesicles also become vascularized quite like the rest of the pellucid area, and a pair of **ventral aortae** is formed beneath the fore-gut. Immediately posterior to the anterior intestinal portal these vessels diverge, passing into the vascular network as the rudiments of the vitelline veins.

CHAPTER XXXII.

THE FIRST HALF OF THE SECOND DAY

(Twenty-four to Thirty-six Hours)

It is well at this point to continue with the vascular system, thus giving a connected account of how the heart and the various blood vessels are formed.

The paired primordia of the heart, already mentioned, grow mesiad and fuse, to form a thin-walled tube which becomes the **endothelial lining** of the heart (Fig. 275). The muscular walls of the heart are formed by the addition of an external layer of mesoderm. This is understood the better by noting that the splanchnic mesoderm on each side forms a fold around the endothelial rudiment and fuses both dorsally and ventrally in the midline. For a very short period this fusion remains on the dorsal aspect, being called the **dorsal mesocardium.** The ventral fusion forms the **ventral mesocardium.** The ventral mesocardium breaks away almost immediately, the dorsal mesocardium remaining for a longer time, but then it also disappears with the exception of the portion at the anterior and posterior extremities of the heart. The heart is now a short median tube made up of endothelial and rudimentary muscular layers, suspended in a cavity, later to be called the **pericardial cavity.** Anteriorly, the heart-tube is continuous with a short pair of vessels extending into the head-fold—the ventral aortae already mentioned. Posteriorly

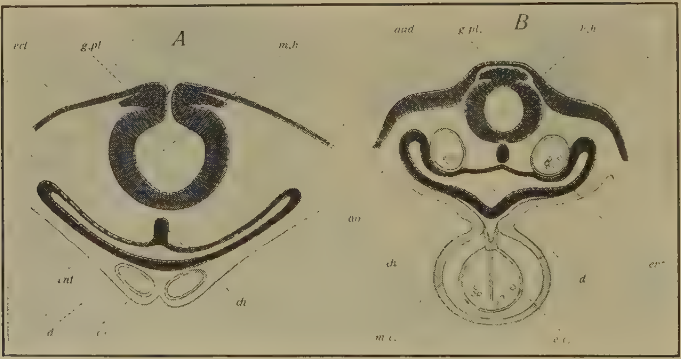


Fig. 275.

Cross section of *A*, through head of 2 day chick embryo in the region of the mid brain. *B*, through posterior region of head at the end of 3 days. *ao*, aorta; *aud*, otic anlage; *c*, heart anlage; *ch*, notochord; *d*, fore-gut; *ec.*, endocardium; *ect*, ectoderm; *ent*, entoderm; *g.pl.*, neural crest; *h.h.*, hindbrain; *m.c.*, myocardium; *m.n.*, midbrain. (After Marshall.)

the heart-tube is continuous with the vitelline or omphalo mesenteric veins (Fig. 276).

The two vessels of the heart (Fig. 283) come in contact so as to form the letter V, the point of the V being toward the head of the embryo. The arms continue fusing until a Y-shaped stem has been developed, with the stem toward the head.

Although the two tubes unite in the manner just mentioned, their cavities remain distinct for a short time, the endothelial lining forming two distinct cavities until a short time after the muscular walls have fused. The muscular walls themselves are not complete on the dorsal side for a short time, but as soon as the tubes have thoroughly fused, the walls also complete their function.

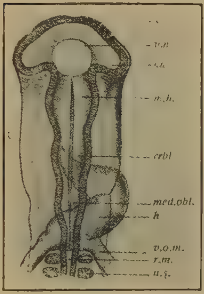


Fig. 276.
Anterior region of 2½ day chick embryo. *au*, optic vesicle; *crbl*, cerebellum; *h*, heart; *m.h.*, vesicle of midbrain; *med.obl.*, medulla oblongata; *r.m.*, spinal chord; *u.s.*, primitive segment; *v.h'.*, primary vesicle of the forebrain; *v.o.m.*, omphalo-mesenteric vein; *x*, anterior wall of primitive forebrain which later expands into the cerebrum. (After von Mihalkovics.)

It is the stem of the Y which forms the true heart, the two arms being continuous with the large vitelline veins which carry blood **to** the heart from the vascular area. The caudal end of the heart is then said to be venous, while the cephalic end is known as the arterial end.

At the thirty hour period the heart is a short straight tube attached to the ventral wall of the fore-gut or pharynx. The point where the vitelline veins diverge is at the hindermost angle of the head-fold. As the head-fold is pushed farther and farther back, the straight portion of the Y is lengthened, but as the tubular heart seems to grow more rapidly than does the place to which it is attached, it is bent into a loop, with its convexity toward the right side of the embryo. This looping is made possible by the fact that the heart has by this time lost all connection with the wall of the fore-gut and remains attached only at both ends.

It is even before this period that the heart begins to beat, the pulsations beginning at the venous end and passing to the arterial end. In fact, the beating began before any muscular differentiation could be observed in the heart region.

The cephalic end of the heart is known as the **bulbus arteriosus.** The bulbus branches immediately into two narrow vessels, the **aortic arches,** one passing upward on each side of the digestive tract to the dorsal side of the embryo and then running tailward as the paired **dorsal aortae** (Fig. 277). These vessels lie close to the notochord under the somites, and extend as separate vessels almost to the tail, where a larger branch than the vessel itself is given off from each. These two large branches are the **vitelline arteries,** which carry the blood **from** the heart back to the vascular area.

THE DIFFERENTIATION OF THE BRAIN REGION

At twenty-seven hours, the more cephalic end of the neural tube has become considerably enlarged as compared with the more caudal portion. The walls are thicker and the lumen larger. This portion is to become the brain proper, the portion in which the lumen has not enlarged becoming the spinal cord. A picture of the brain at this time (Figs. 278 and 282) will show three **primary vesicles** or lumen-enlargements together with what these three vesicles later become. The most anterior of the three primary vesicles is known as the **fore-brain**, or **prosencephalon.** The mid portion is called the **mid-brain** or **mesencephalon,** while the most posterior vesicle forms the **hind-brain** or **rhombencephalon.** The rhombencephalon is continuous with the spinal cord.

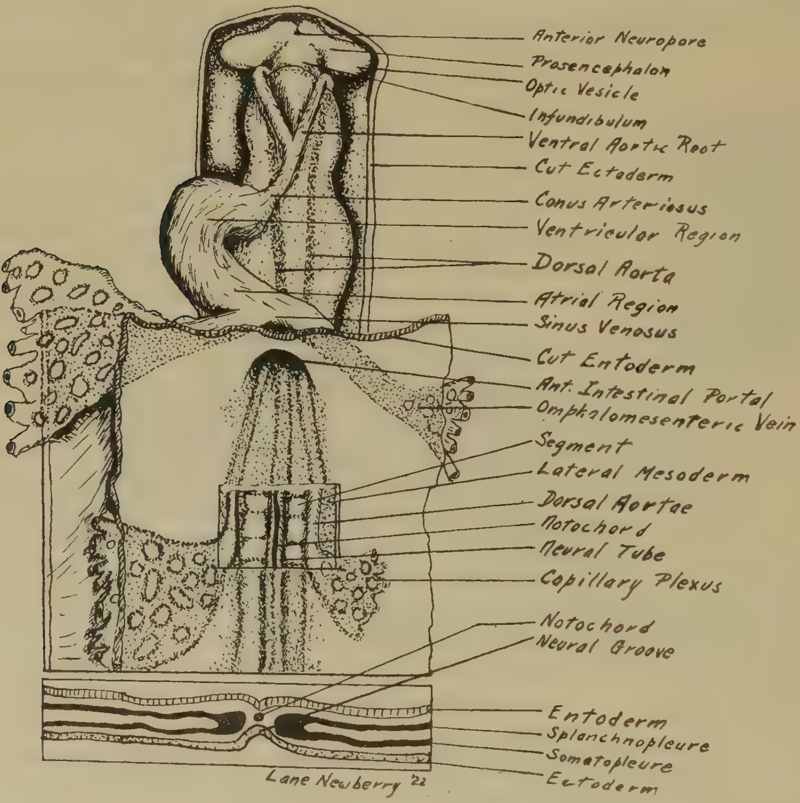


Fig. 277.

Diagrammatic ventral view of a 35-36 hour chick embryo. Compare with Figures 279 and 280. (Modified from Prentiss.)

As all further developments of the brain arise from these three primary regions, it is of the utmost importance that these primary regions be grasped fully.

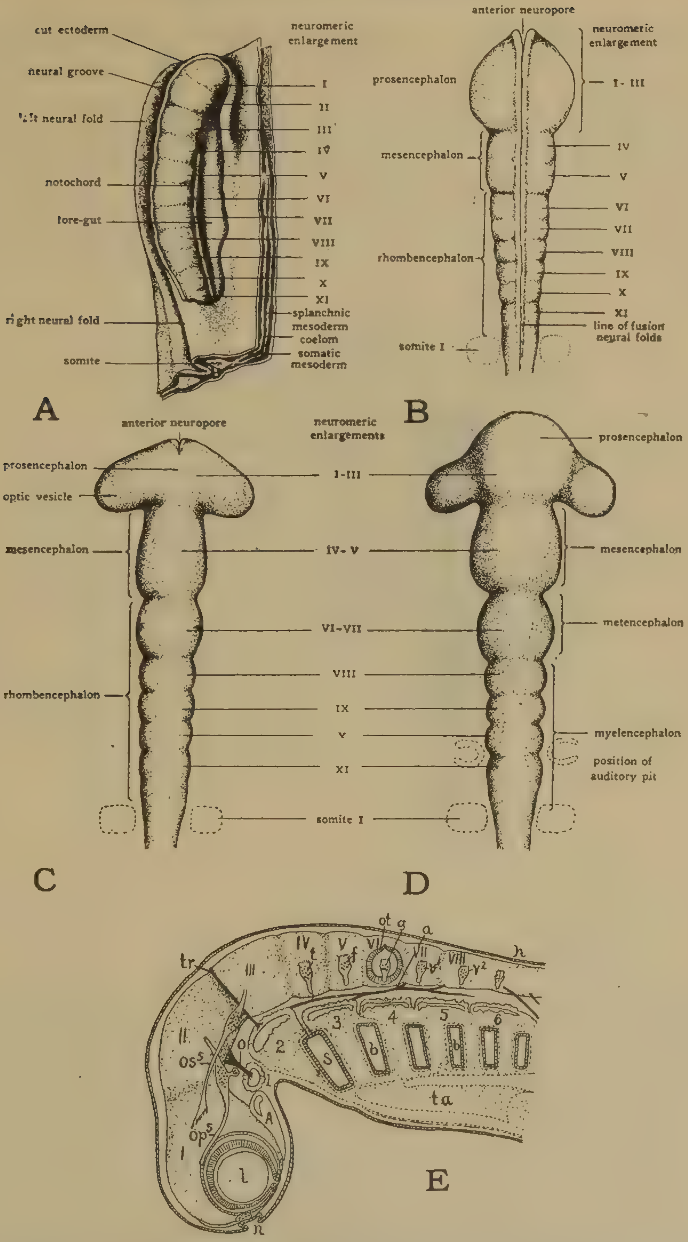


Fig. 278.

Diagrams showing neuromeres in brain region of the neural tube. *A*, lateral view of neuralplate of 24 hour chick embryo. *B*, dorsal view of brain from a 26-27 hour (7 somite) chick embryo. *C*, dorsal view of brain from a 30 hour (10 somite) chick embryo. *D*, Dorsal view of brain from a 36 hour (14 somite) chick embryo. *E*, Diagram of the segments (neuromeres, myotomes, etc.) of the head in longitudinal section. *A*, anterior myotome; *a*, abducens nerve; *b*, branchial clefts; *f*, facial nerve; *g*, glossopharyngeal nerve; *h*, hypoglossal nerve; *l*, lens surrounded by layers of eye; *n*, nasal pit with the terminal nerve nearby; *o*, oculumotor nerve; op^5, ophthalmicus profundus part of fifth nerve; os^5; ophthalmicus superficialis part of the fifth nerve; *ot*, otocyst; *s*, spiracular cleft; *t*, trigeminal nerve; *ta*, truncus arteriosus; *tr*, trochlearis nerve; I-VIII, neuromeres; 1-6 myotomes. (*A-D*, from Patten after Hill, *E*, from Kingsley after Neal.)

From the lateral walls of the prosencephalon the primary **optic vesicles** push out as a pair of rounded pockets, the lumen of each being directly continuous with that of the fore-brain.

The notochord extends as far as the **infundibulum** (Fig. 282, A), (a depression in the floor of the fore-brain), so that all regions of the brain lying anterior to it are called **pre-chordal,** while the rhombencephalon, mesencephalon, and the part of the prosencephalon posterior to the infundibulum, which lie dorsal to the notochord are called **epichordal.**

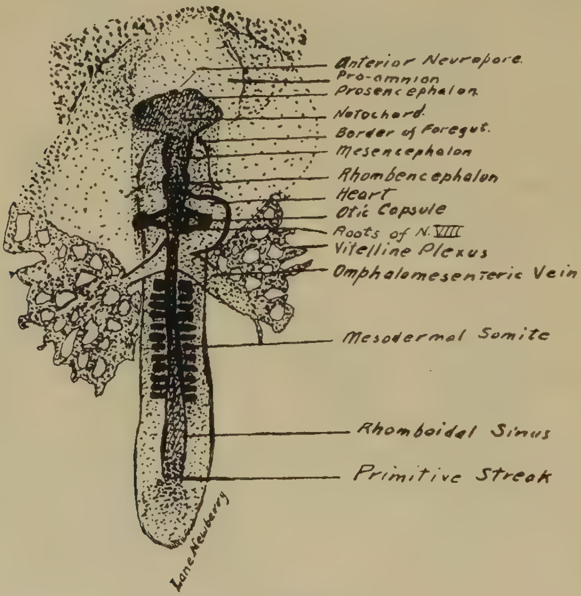


Fig. 279.

33 hour chick embryo (12 somites).

As has been noted some time back, the most anterior region where the neural tube closes is called the **neuropore.** The neuropore is still open at this time and remains so, although gradually becoming smaller until after the thirty-third hour period, but even then, there is a scar-like fissure. As we know of no structure arising from the neuropore, it is important only as a sort of landmark in describing the location of brain structures.

At this time the neural tube is closed back as far as the somites, and it is of nearly uniform diameter, although, posterior to the last formed somites, the neural tube is still open, and the neural folds can be seen to diverge on either side of Hensen's node (Fig. 279).

It will be remembered that the first four somites formed are also a part of the head region. Therefore it can be understood that as the neural folds approach each other in the midline, in the region of Hensen's node, an opening remains, rhomboidal in shape. This is the **rhomboid sinus.**

In lower forms, there is an opening from the neural canal into the digestive tract known as the **neurenteric canal,** or **posterior neuropore,** at the point where the blastopore does not close until after it is surrounded by the neural folds. In the chick the **primitive pit** represents this region of the neurenteric canal.

Shortly after the twenty-seventh hour period, and as soon as the caudal end of the chick can be definitely outlined, the primitive streak disappears entirely.

LENGTHENING OF THE FORE-GUT

The crescent-shaped margin of the anterior intestinal portal grows more and more caudad, first because the margin from each side grows toward the midline to fuse with the other side, thus lengthening the fore-gut by adding to its floor, and pushing the crescentic margin caudad; and second, all structures anterior to the anterior intestinal portal are elongating so rapidly that the portal is bound to lie further and further caudad from the cephalic end of the embryo.

These two processes together cause the space between the subcephalic pocket and the margin of the anterior intestinal portal to become elongated, and it is in this enlarging space that the pericardial portions of the coelom extend, and in which the heart comes to lie.

CHAPTER XXXIII.

THE SECOND HALF OF THE SECOND DAY

(Thirty-six to Forty-eight Hours)

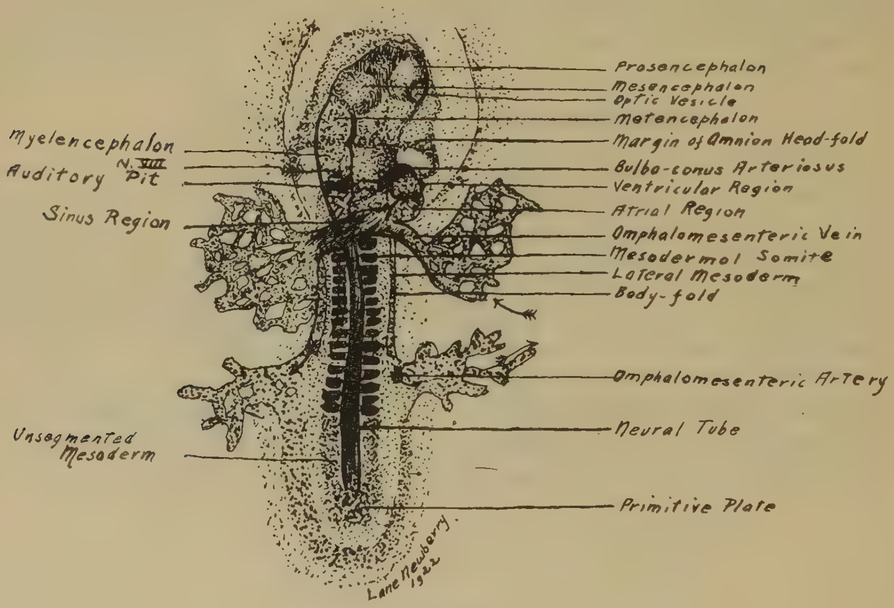


Fig. 280.

38 to 43 hour chick embryo. (15 somites.)

It is at this period where the caudal end of the embryo becomes definitely outlined by the formation of a tail fold and lateral folds similar to the head fold.

THE BRAIN

Going on from where we left off in our discussion of the formation of the three primary brain vesicles, we find that at this period the neural canal has completely closed, even the rhomboidal sinus has fused. The primary vesicles have enlarged, and their lines of demarcation have become more definite. The fore-brain has grown forward as an unpaired vesicle from which the cerebral hemispheres are to develop. The walls of the brain itself lie under the ectoblast, while between the walls and the ectoblast there can be seen a small amount of mesoblast which is to form the skull.

The optic vesicles have become elongated and definite constrictions

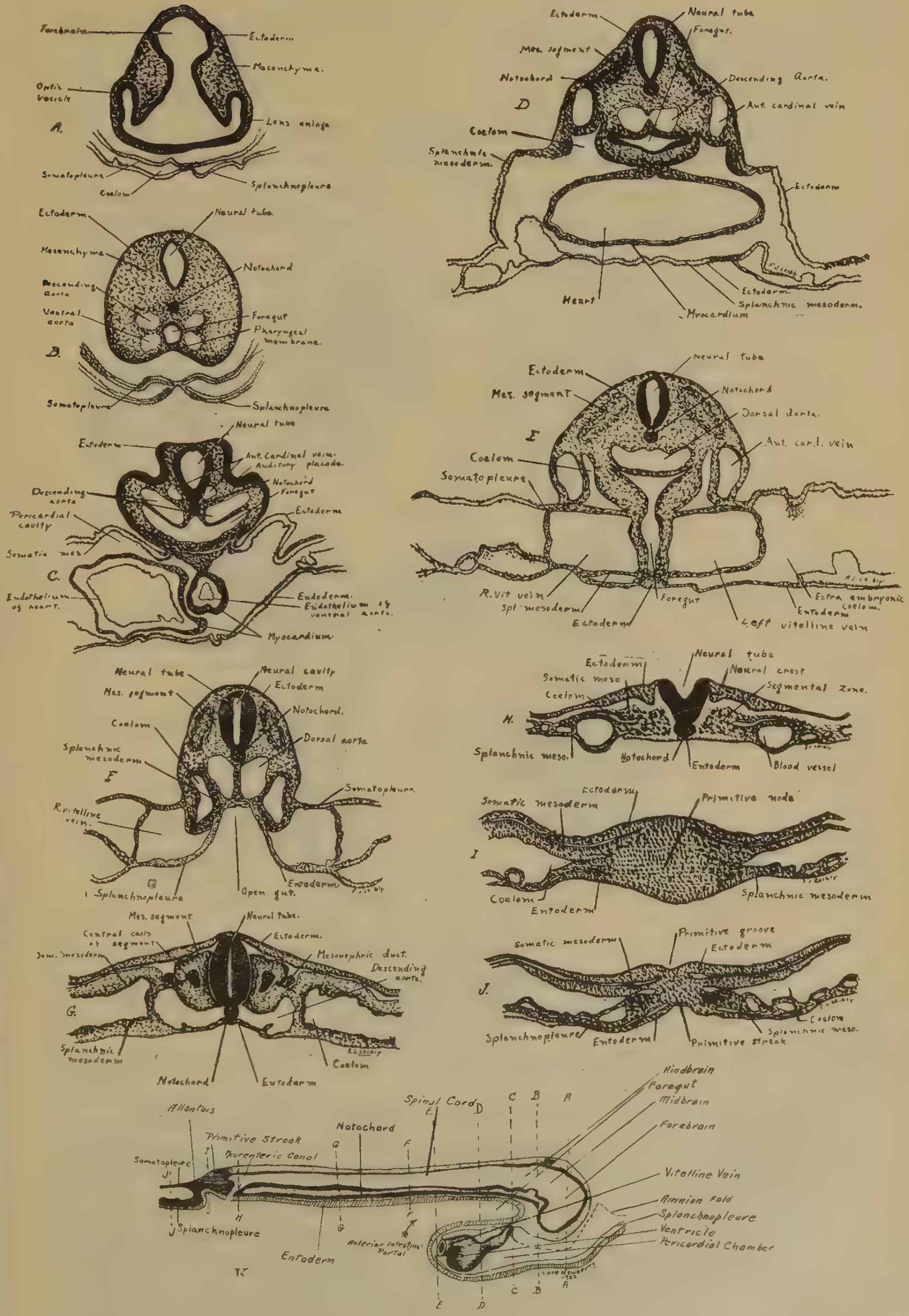


Fig. 281.

Transverse sections through a 36 to 38 hour chick embryo. *A*, Through forebrain; *B*, through the pharyngeal membrane; *C*, through hindbrain and auditory placodes; *D*, through posterior end of heart; *E*, through the intestinal portal; *F*, just posterior to *E;* *G*, through the fourteenth pair of segments; *H*, through the rhomboidal sinus; *I*, through Hensen's node; *J*, through the primitive streak; *K*, medial longitudinal section of a 36 to 38 hour chick embryo. (This drawing must be studied very carefully and thoroughly to understand the transverse sections which are cut through the levels marked.)

are formed at their bases so that they now form **optic stalks,** which bend downward and backward.

The cranial nerves can be seen developing at this period also.

It is at this time that the first bend or **flexure** takes place in the brain, cephalad to the notochord (Fig. 282). This is the **cephalic flexure.**

If the neural plate be examined at the end of the first day, eleven enlargements (Fig. 278) will be seen with definite constrictions between them. These enlargements are known as **neuromeres** and are really an uncompleted segmentation.

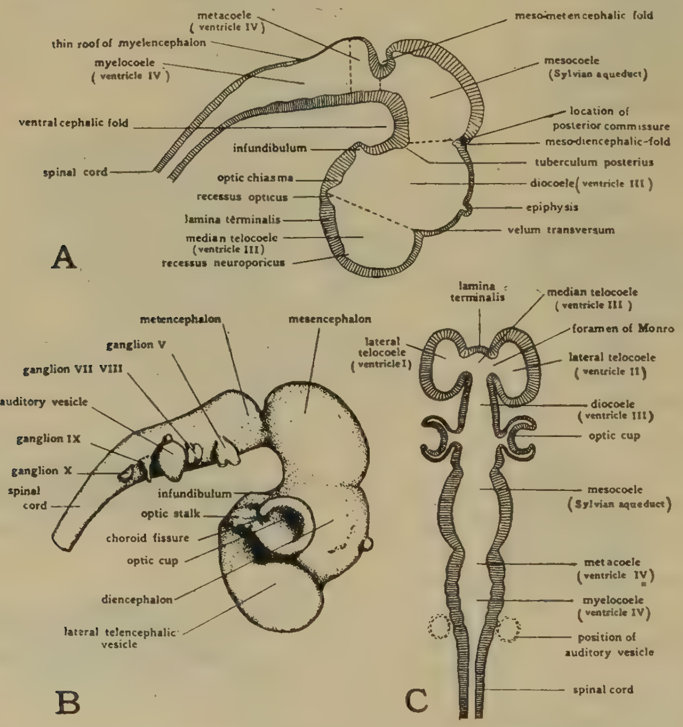
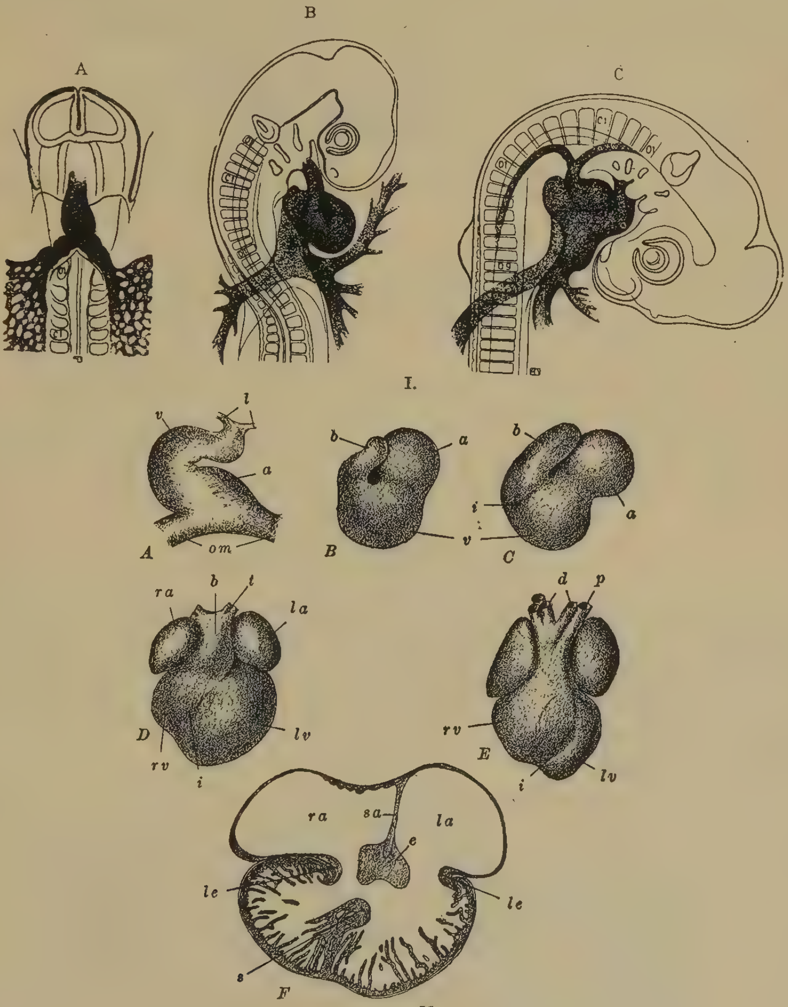


Fig. 282.

Diagrams of brain of 4-day chick embryo. Dotted lines show arbitrary boundaries between vesicles. *A*, longitudinal; *B*, right side; *C*, horizontal section. (From Patten, after V. Kupffer.)

The literature is filled with many varying and unsatisfactory theories as to what becomes of each neuromere, but as yet nothing can be demonstrated satisfactorily. It is conceivable, however, that as in the crayfish, for example, where we assume that each separate appendage or pair of appendages bespeak an embryological segment, so in vertebrates, where optic vesicles grow from the fore-brain, we may assume a fusion of several segments.

At about thirty-three hours, the floor of the prosencephalon has a depression formed in it which is to become the **infundibulum.** This is an important seat of future development. It must, therefore, be studied carefully so that it can be recognized in future work.



II.

Fig. 283.

I. Views to show the posterior displacements of the heart in the chick embryo. *A*, The heart lies ventral to the first segment. This is the region where the future hindbrain will form. *B*, The point of bending loop of the ventricle is at the seventh cervical segment. *C*, The bending of the loop of the ventricle is now at the ninth thoracic segment. (From Corning after Duval.)

II. The development of the heart of the chick. *A-E*, ventral views of the heart; *A*, of a forty-hour embryo; *B*, of a 2.1 mm. embryo; *C*, of a 3.0 mm. embryo; *D*, of a 5.0 mm. embryo; *E*, of a 6.5 mm. embryo. *F*. Frontal section through the heart of a 9 mm. embryo. *a*, Auricle; *b*, bulbus; *d*, roots of dorsal aorta; *e*, median endothelial cushion; *i*, interventricular groove; *la*, left auricle; *le*, lateral endothelial cushion; *lv*, left ventricle; *om*, vitelline artery; *p*, left pulmonary artery; *ra*, right auricle; *rv*, right ventricle; *s*, interventricular septum, *sa*, interauricular septum; *t*, roots of aortic arches; *v*, ventricle. (*A*, *F*, after Hochstetter; *B* to *E* after Greil.)

At about thirty-eight hours, the three primary vesicles divide to form five vesicles (Fig. 278, 282).

The prosencephalon divides into **telencephalon (end-brain)**, and **diencephalon ('twixt-brain)**; the mesencephalon remains undivided, while the **rhombencephalon** divides into **metencephalon (cerebellum and pons)**, and the **myelencephalon (medulla oblongata).**

The telencephalon has not yet completely separated from the diencephalon, but there is a median enlargement showing where the division will take place.

The two most anterior neuromeres of the original rhomencephalon form the metencephalon, and the posterior four neuromeres form the myelencephalon.

At thirty-five hours, the auditory pits begin growing as thickened ectoderm known as **auditory placodes** on the dorso-lateral surface opposite the most posterior inter-neuromeric construction of the myelencephalon. At thirty-eight hours, the general level of the ectoderm has become depressed to form a pair of cavities known as **auditory pits.** The pits seem to recede until they become closed vesicles, and separate from the superficial ectoderm, although it will not be until later that they form a definite connection with the central nervous system.

TORSION

At about the same time the cephalic flexure begins, there is also the beginning of a twisting of the entire embryo (Fig. 280), although at this time the twisting is only observable in the head region. The bending of the cephalic region downward is, as already stated, called **"flexion."** The twisting of the embryo from its ventral aspect to its side is known as **"torsion."**

As the yolk lies directly beneath the embryo, it can easily be understood that any bending ventrad would be stopped by the large mass of inert yolk beneath, so that if there is to be any considerable bending at all, the entire embryo must turn on its side, and this it does in all eggs which possess considerable yolk, though it does not necessarily come to lie on the same side in all amniotes. The chick turns so that its left side lies next to the yolk.

Torsion begins in the head region and gradually and slowly extends the full length of the body, so that a whole mount, after torsion is completed, shows the embryo lying on its left side with head and tail close together, the entire embryo forming from one-half to about three-fourths of a circle.

THE CIRCULATORY SYSTEM

By the end of the second day, the heart has become still more twisted, and is now S-shaped with the venous end above and behind the arterial end, so that both ends lie close together with the loop as an intermediate portion between. The venous portion forms a swelling which later becomes the **auricles**, while the arterial end also enlarges to form the **bulbus arteriosus**. The **point** of the loop becomes the **ventricles** (Fig. 283).

It is toward the end of the second day that the pair of aortic arches

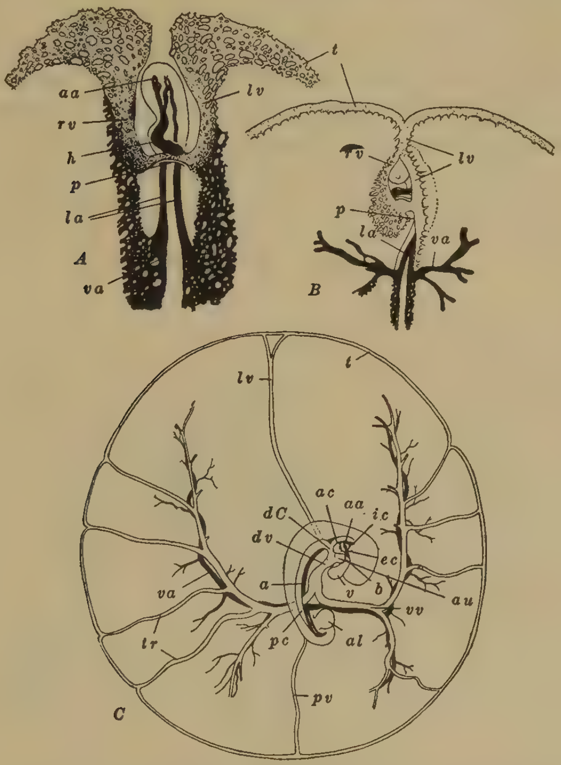


Fig. 284.

Diagrams of the circulation in the chick embryo and area vasculosa. The vascular network of the area vasculosa is omitted for the most part. *A*. Anterior and central parts of the embryo and vascular area at about thirty-eight hours (sixteen pairs of somites). Viewed from beneath. *B*. Median and anterior parts of vascular area and embryo at about seventy-two hours (twenty-seven pairs of somites). Viewed from beneath. *C*. The main vascular trunks of the fourth day. *a*, Dorsal aorta; *aa*, aortic arches (first and second in *A*, second, third and fourth in *C*); *ac*, anterior cardinal vein; *al*, allantois; *au*, auricle; *b*, bulbus arteriosus; *dC*, ductus Cuvieri; *dv*, ductus venosus; *ec*, external cartoid artery; *h*, heart; *ic*, internal cartoid artery; *la*, lateral dorsal aorta; *lv*, left anterior vitelline vein; *p*, anterior intestinal portal; *pc*, posterior cardinal vein; *pv*, posterior vitelline vein; *rv*, right anterior vitelline vein; *s*, sinus venosus; *t*, sinus terminalis; *tr*, venous trunks of the area vasculosa; *v*, ventricle; *va*, vitelline artery; *vv*, vitelline or omphalomesenteric vein. (From Kellicott after Popoff and Lillie.)

which have bent dorsad (and continue separately as the paired dorsal aortae) unite behind the head to form a single vessel which comes to lie directly beneath the notochord. However, after running but a short distance caudad, the single aorta again divides into two vessels from which the large vitelline artery, already mentioned, is given off on each side. The dorsal aortae, now greatly diminished in diameter, continue into the tail.

The first pair of aortic arches formed are called the **mandibular** aortic arches (Fig. 284).

A second pair now form behind the first, and before the close of the day there may be still a third pair, all of which connect in a similar manner to the first with the bulbus arteriosus and the dorsal aorta.

The sinus terminalis is now also much better developed than before and a true circulation has been established, which can carry the yolk-food-granules (after these have been converted into usable food) to the embryo.

It is essential that a somewhat detailed knowledge of the circulation be obtained.

The blood is brought to the heart by the vitelline veins (Figs. 277, 284). The heart then contracts and forces it through the aortic arches into the dorsal aorta. Here it passes tailward, a small portion going into the tail itself, but the greater part is carried to the vascular area. There are two ways in which the blood now gets back into the vitelline veins. First, it may pass directly to the veins from the arteries through the connecting capillaries, or, second, it may pass into the sinus terminalis at a middle point on each side, and then pass forward and backward through this large vessel. The greater portion, however, in this second method passes forward toward the head from where it is returned to the heart through two large parallel vessels. The part which passes backward is again distributed to the vascular area as there are no connecting vessels with the tail of the embryo. The vitelline veins and arteries run parallel to each other, though the veins lie a little forward from the arteries.

In the embryo itself, the **cardinal veins** are the main afferent vessels. At thirty-eight hours the **anterior cardinals** can be seen. These are a pair of vessels which return the blood from the head of the embryo to the heart. The **posterior cardinals** are also paired, and return blood from the caudal region.

Both anterior and posterior cardinal veins unite on each side of the body to form a short common vessel before entering the heart, the right and left **ducts of Cuvier,** or **common cardinal veins.** These Cuvierian ducts then turn ventrad on each side of the fore-gut and enter the sinus venosus at the same point the omphalomesenteric veins enter.

The omphalomesenteric veins [so called because they pass through the umbilicus (navel) as umbilical vessels connecting the offspring with the mother in the higher forms], are established in the chick from thirty-three to thirty-six hours' incubation. They are postero-lateral extensions of the self-same endocardial tubes which formed the heart. They extend laterad to meet the vessels which develop in the vitelline plexus outside the embryo, and which extend inward toward the embryo. The **omphalomesenteric veins (those lying within the embryo)** eventually become one with the **vitelline veins (those lying in the extra-embryonic area)** and thus establish the **afferent vessels of the vitelline circulation.**

The **efferent** vessels develop at about forty hours. They have a dual origin. The embryonic vessels consist of the branches of the dorsal aortae which extend outward where they meet with the extra-embryonic arteries growing toward the embryo to meet with, and become confluent with, the embryonic efferent vessels, now being known as the **omphalomesenteric arteries.**

It is at about the thirty-second hour that the heart begins to contract irregularly, although the maximum rate (150 to 180 per minute), is not reached until after 100 hours of incubation.

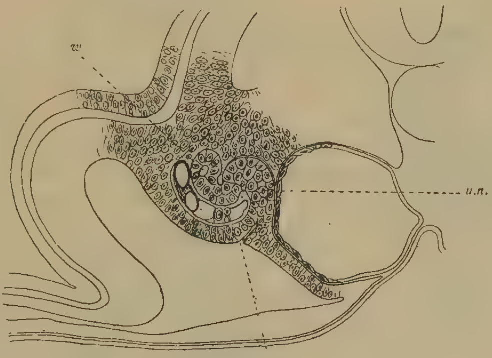


Fig. 285.

A portion of a cross section of a 54 hour chick embryo through the solid anlage of the pronephric tubules in the region of the beginning of the Wolffian duct. The nephrostomes are just beginning to form. *neph.st.*, nephrostome; *u.n.* pronephric ducts; *w*, Wolffian duct. (After Kölliker.)

THE PATH OF A BLOOD-CORPUSCLE

It is well to follow a corpuscle through its entire circulation at this time. With the contraction of the heart, the corpuscle will be sent through the ventral aortae, along the dorsal aortae, out through the omphalomesenteric arteries to the plexus of vessels on the yolk.

It will be remembered that there are various membranes surrounding the yolk. These contain many small vessels which absorb the yolk. As there must be an oxygenation of the blood, this vitelline circulation must also assist in this function until the allantois, shortly to be described, is formed. This aeration can be accomplished on account of the great area these membranes cover, which permits a wide field from which to draw the oxygen that permeates through the egg shell and the albumen surrounding the yolk.

After the yolk has been absorbed as food-material, and the blood has become oxygenated, the blood is collected into the sinus terminalis and the vitelline veins. The latter converge toward the embryo from all parts of the vascular layer, and empty into the omphalomesenteric veins, which return the blood to the heart.

The blood which has been sent to the various parts of the embryo has in the meantime been returned from the head region by the anterior cardinals, and from the caudal end by the posterior cardinals, the anterior and posterior cardinal of each side having met to form a short **common cardinal (duct of Cuvier)** through which the blood flows into the sinus portion of the heart.

There is therefore a **mixed circulation** in the heart, consisting of both embryonic and extra-embryonic blood. The extra-embryonic, of course, is the richer in both food and oxygen supply.

THE EXCRETORY SYSTEM

After about ten somites have been formed, the beginnings of the excretory system are visible.

It will be remembered that the mid-region of the partially segmented mesoderm, known as the mesomere, is to become the excretory system. It can be noted first as a solid cord of cells extending for two or three somites (Fig. 285). This will be called the **Wolffian Duct** as soon as a lumen forms.

During the second half of the second day, this solid rod elongates both headward and tailward, the more tailward portion becoming free and lying between ectoblast and mesoblast. A lumen appears toward its center and extends headward and tailward simultaneously. About the beginning of the fourth day the duct definitely opens into the cloaca.

The **Wolffian body** also makes its appearance on the second day, but it will be better understood if the description is reserved until later.

CHAPTER XXXIV.

EXTRA-EMBRYONIC MEMBRANES

It will be remembered that when the mesoderm splits into a somatic and a splanchnic layer, it extends out over the yolk so that there is no definite line of demarcation separating embryo from the surrounding media. First, the head fold appears, delimiting the embryo at the cephalic end, and later the tail-fold and lateral fold do the same for the caudal and lateral regions, so that after these folds have bent downward and under the embryo, and almost separated the embryo from the yolk, we speak of the space between the somatic and splanchnic layers as the **intra-embryonic coelom** and the **extra-embryonic coelom**, according to which portion lies within, and which portion lies outside, the embryo.

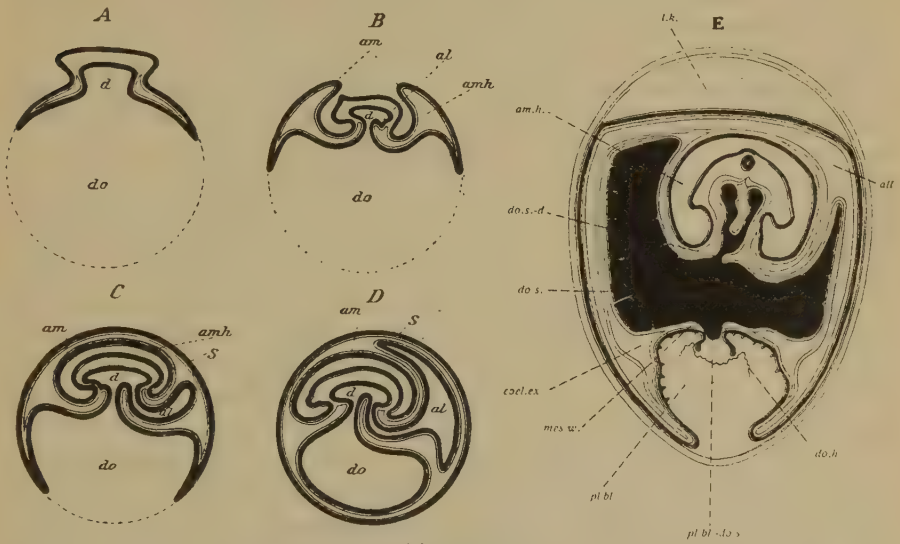


Fig. 286.

A, B, C, D, four stages of development of the embryonic membranes in birds. *al,* allantois; *am,* amnion, (in Fig. *B.*, this forms folds which give rise to both amnion and serosa); *am.h.*, amniotic cavity; *d,* digestive cavity; *do,* yolk-sac.

E. Cross section through entire egg (including shell). *all,* allantois which begins developing at the blunt end of egg; *am.h.*, amniotic cavity; *coel.ex.*, extra-embryonic coelom; *do.s.*, yolk-sac showing development of mid-gut—*do.s.d.*; *do.h.*, covering of yolk; *l.k.*, air-chamber; *mes.w.*, extensions of the mesoderm between the communicating opening of yolk sac and amniotic cavity—*pl.bl.* The remaining portion of the yolk covering (*do.h.*) closes the passage. These mesodermal extensions as well as the lower tips, at the pointed end of the egg, close later and thus form a closed amniotic cavity. *pl.bl.*, amniotic cavity which develops from the ectoderm with tiny projections on the inner side. It is in this cavity that the remaining yolk is found; *pl.bl.-do.s.*, Communicating passage between amniotic cavity and yolk-sac. (*A, B, C, D,* after Boas, *E,* after Duval.)

The limiting folds which are continuous with the head fold and extend on each side of the embryo as the **lateral folds**, form the line of demarcation known as the **lateral limiting sulci.**

In this chapter we are concerned with the extra-embryonic membranes which are developed from the various layers in the extra-embryonic region. The membranes themselves are four in number: the **yolk-sac,** the **amnion,** the **serosa,** and the **allantois** (Fig. 270).

THE YOLK-SAC

This is the first of the extra-embryonic membranes to appear. It must be remembered, that as the splanchnopleure grows outward from the embryo, it surrounds the yolk, thus forming the yolk-sac. The yolk itself forms the floor of the primitive gut.

As the underfolding in the head-region separates the head from the remaining blastoderm, it grows caudally and forms an entodermal floor to the primitive gut, and the part which thus obtains this entodermal floor is called the **fore-gut.** So, too, in the tail region a little later (about the third day), the tail folds under the posterior end of the embryo and the part which thus obtains an entodermal floor in that region is called the **hind-gut.** The portion between fore-gut and hind-gut is the **mid-gut,** which is, of course, that region where the yolk is still the floor. As the fore-gut and hind-gut become larger and extend toward each other, the mid-gut occupies less and less area, until there is merely a little duct something like the small end of a funnel, the larger end of the funnel being the extended splanchnopleure surrounding the yolk. In other words, the mid-gut consists only of the **opening of the yolk-stalk,** which latter is made up in turn of the walls of the splanchnopleure drawn together at this point.

As the neck of the yolk-sac is thus constricted, the omphalomesenteric arteries and veins, which extend throughout the region where the constriction takes place, have likewise been drawn into the constricted area, and pass to and from the embryo through the yolk-stalk, side by side.

The yolk is now covered with a vascular network spreading throughout the splanchnopleure of the yolk-sac, so that the entire food supply of the embryo comes to lie in a sac with this circulation of its own definitely attached to the mid-body region, though as far as we know, no yolk granules pass directly into the embryo, all of it being absorbed by the vascular network. In older embryos, the yolk-sac even folds considerably, so that a still greater expanse of vascular area is established.

The white albuminous portion of the egg rapidly loses the water it contains, and is absorbed by the extra-embryonic membranes.

Ultimately (about the nineteenth day) the yolk-sac is completely enclosed within the embryo, and then rapidly disappears until it is entirely gone by the sixth day after hatching.

THE AMNION AND THE SEROSA

While the splanchnopleure forms the yolk-sac, it is the somatopleure, lying outside the embryo, from which both amnion and serosa are derived.

At about thirty hours, the first observable portions of the amnion appear as a crescentic fold with the concavity toward the head of the embryo. This fold must not be confused with the head fold of the chick which folds under the embryo.

The head at this time sinks into the yolk to a slight degree, just as the extra-embryonic somatopleure anterior to the head is thrown into the head-fold of the amnion. As the embryo grows anteriorly and the somatopleure caudally, the amniotic fold which is thus folded upon itself, forms a double-walled cap over the head of the embryo, gradually extending more and more caudad. The caudally directed limbs of the head-fold of the amnion continue growing posteriorly on each side of the embryo, where they are known as lateral amniotic folds. These grow dorsad and mesiad, finally meeting in the midline.

During the third day, the amniotic tail-fold develops and grows cephalad to meet the structures just mentioned, thus forming a complete envelope for the embryo. The place where the various amniotic folds meet is called the **amniotic raphe.**

The amnion is now a completed saccular structure filled with a fluid in which the embryo is free to move about and change positions. In all probability, this ability of free movement also prevents adhesions and consequent malformations.

It is to be noted that the manner in which the amniotic folds came into existence has caused the innermost portions to be ectodermal. This ectodermal layer is continuous with the ectoderm of the embryo.

Likewise, the manner of the somatopleure folding upon itself, as it does, causes **two walls to cover the embryo.** The inner one is the ectodermal layer just mentioned and the outer one is known as the **serosa.** There is a **sero-amniotic cavity** between the two.

The somatopleure now extends peripherally until the entire yolk-sac, and eventually the embryo as well, is covered with serosa.

The allantois extends between serosa and amnion.

THE ALLANTOIS

This structure differs from the amnion and yolk-sac in that it develops **within the embryo proper,** though it does extend out into the extra-embryonic region as it develops.

About the third day, the allantois develops by an outpushing of the ventral wall of the hind-gut (entoderm), pushing the splanchnopleure ahead of it, so that we may say it is composed of splanchnopleure with an entodermal lining. The following day it pushes out of the embryo into the extra-embryonic coelom, the attached end lying caudal to, and parallel to, the yolk-stalk. The proximal portion is called the **allantoic stalk,** and the extended bladder-like distal portion the **allantoic vesicle.**

It grows very rapidly from the fourth to the tenth day, and extends into the sero-amniotic cavity in a flattened manner. Ultimately it encompasses the entire embryo and yolk-sac, and in so doing the mesodermic layer of the allantois fuses with the layer of mesoderm of the serosa which comes to lie in direct contact with it. This means that there is thus formed a double layer of mesoderm, the serosal portion being derived from the somatic mesoderm, and the allantoic portion derived from the splanchnic mesoderm. A very rich vascular network now develops between these two layers connected with the vascular circulation by the allantoic arteries and veins.

The allantois thus becomes an organ of respiration, as well as circulation, to the developing embryo. As the allantois lies just beneath the porous shell, there is a wide area presented for an exchange of the carbon dioxide developed within the embryo and the oxygen from the outer world.

In addition to this function, however, the allantois also serves as a reservoir for the secretions from the excretory organs of the embryo, and likewise takes part in absorbing the albumen.

THE CHORION

The serosa will become a part of the **chorion** in the higher forms, and consequently, should be clearly understood at this point. The allantoic vessels mentioned above and the mesoderm which lies between the serosa and amnion, later fuse with the inner layer of the serosa to form the **chorion,** which is the embryo's organ of attachment to the uterine wall of the mother. How very important the allantoic circulation becomes in mammals may be surmised by realizing that there is little yolk in mammalian eggs. This forces the embryo to receive all of its nourishment from the blood of the mother through the uterine walls. The allantoic circulation thus performs the function of the vitelline circulation also.

CHAPTER XXXV.

DEVELOPMENT OF THE THIRD DAY

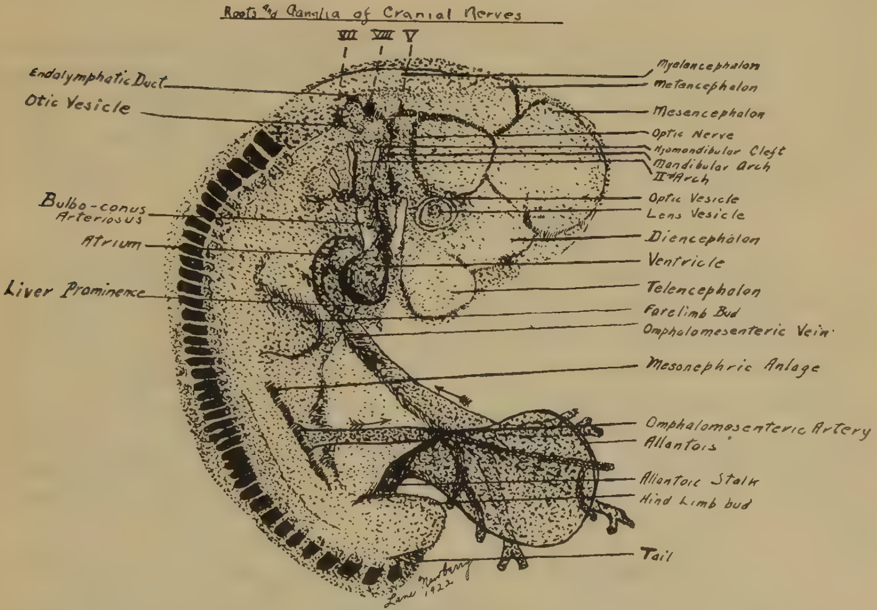


Fig. 287.

64-hour chick embryo. (41 somites.)

It is upon this day that more structures make their first appearance than on any other single day of the chick's entire embryonic life. The blastoderm itself has increased in size so that it covers almost one-half the yolk surface. The white of the egg has decreased in amount so that the vascular area has been brought closer to the surface under the shell, making aeration of the blood easier.

The sinus terminalis reaches its greatest functional activity during this day, and the vitelline veins have been brought in close contact with the vitelline arteries by the growth of the embryo.

The blood, which the vitelline or omphalomesenteric arteries bring to the sinus terminalis, still flows headward and tailward as before. The portion flowing toward the head returns to the embryo through two large vessels lying parallel to the long axis of the embryo, but sometimes there is only one of these—the one emptying into the left vitelline vein. Even if the two vessels are present, the left is the larger.

It is on the third day also that the single posterior vessel, which also empties into the left vitelline vein and carries blood from the posterior region of the sinus terminalis, makes its appearance.

It will be remembered that it is during this day that the torsion of the embryo takes place from the head region posteriorly, so that **cross sections made from the anterior end will show the embryo turned upon its left side, while in the posterior region it still lies upon its ventral surface.**

The flexion continues also, so that the mid-brain becomes the most anterior region of the embryo. This flexion not only brings the fore-brain in close relation to the heart, but brings optic and otic vesicles opposite each other, it being remembered that the eye-pits form in the fore-brain and the auditory pits in the medulla oblongata.

THE NERVOUS SYSTEM

All parts are growing, and have become larger than on the second day (Fig. 288). The important new developments are as follows: **the epiphysis** appears as a small evagination in the midline on the dorsal surface of the diencephalon. It later becomes the **pineal gland.**

Rathke's Pocket (Fig. 301, 1) is an ectodermal invagination which has folded in just beneath the infundibulum. This pocket soon loses its connection with the outer epithelium, and then becomes permanently associated with the infundibulum to form the **hypophysis** or **pituitary body.**

THE OPTIC VESICLES (Fig. 289)

It will be remembered that these were originally broad stalks directly continuous with the cavity of the fore-brain. The cavity or lumen of the optic stalks is then called an **optocoele** and the cavity or lumen of the prosencephalon is called the **prosocoele.** A constriction formed earlier is very marked at about fifty-five hours. The distal ends have invaginated, forming a double-layered cup. The newly indented layer is termed the **sensory layer,** because it is from this that the sensory layer of the retina is to be formed. The underlying layer is called the **pigment layer,** because it is from this that the pigmented layer of the retina is to arise. The invaginated cups are often called **secondary optic vesicles** to distinguish them from the original vesicles before invagination, the original vesicles being then known as **primitive** vesicles.

The optic cup does not invaginate so as to form an equally rounded edge. The invagination begins at the ventral surface and continues dorsally and toward the midline, so that at the place where the invagination began, there is a region which has no definite lip. The cup, therefore, looks more like a cup that has had this portion broken out. This lipless region is known as the **choroid fissure.**

The invagination continues for the length of the optic stalk, thus

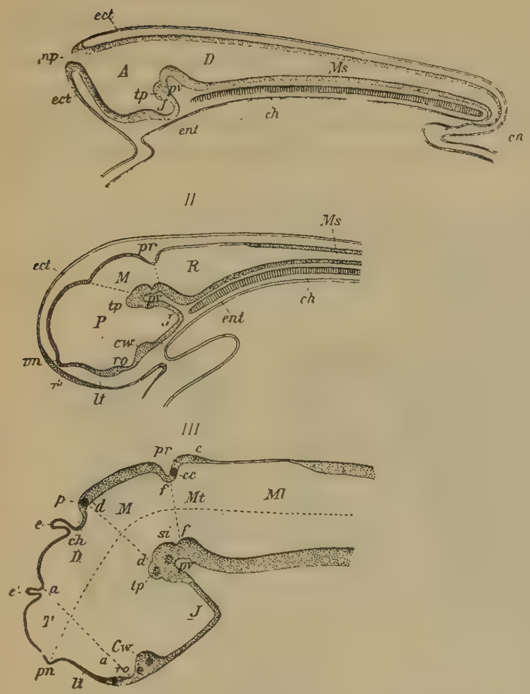


Fig. 288.

Diagrams showing brain development in vertebrates. Longitudinal sections.

I. Before the blastopore closes.

II. At the time three brain regions can be seen.

III. At the time five brain regions have formed. (Compare with Fig. 281.)

A, prosencephalon; *aa*, dividing line between telencephalon and diencephalon; *c*, cerebellum; *cc*, cerebellar commissure; *ch*, (in I and II) dorsal nerve cord; (in III) habenular commissure; *en*, neurenteric canal; *cp*, posterior commissure; *cw*, thickening on optic nerve due to the crossing of fibers (this is the chiasma); *D*, diencephalon; *dd*, line separating diencephalon and mesencephalon; *e*, epiphysis; *e'*, paraphysis; *ect*, ectoderm; *ent*, entoderm; *ff*, line dividing mesencephalon and metencephalon; *J*, infundibulum; *lt*, lamina terminalis; *M*, mesencephalon; *Ml*, myelencephalon; *Ms*, spinal chord; *Mt*, metencephalon; *np*, neuropore; *P*, prosencephalon; *pn*, neuroporic process; *pv*, ventral brain-fold; *R*, rhombencephalon; *r*, thickening of ectoderm which is sometimes said to be the anlage of an unpaired olfactory groove; *ro*, optic recess; *si*, the groove (sulcus intraencephalicus) which forms the hindermost boundary of the midbrain; *T*, telencephalon; *tp*, tuberculum posterius (After von Kupffer.)

forming a fissure in the stalk along which, and in which the optic nerves and blood-vessels come to lie. This is on the ventral surface of the stalk. In the meantime, the optocoele has practically become obliterated, a very small portion alone remaining between sensory and pigment layers in the optic cup. Even these fuse shortly, and then the optocoele disappears entirely.

The eye lens arises independently of the optic vesicles in the ectoderm, close to the vesicle. At forty hours the ectoderm in this region has thickened. The placodes thus formed grow toward and into the optic cups after themselves forming vesicles. The superficial ectoderm from which they arise soon closes again at the point where the lenses have arisen, although a very small opening may still be seen for a short time.

It is well to call particular attention at this point to the similarity of the way in which the lens of the eye and the auditory vesicle develop by a thickening of ectoderm, then insinking and finally completely separating from the superficial ectoderm from which it sprang. The lesson to be brought home, is that once these structures have separated from the superficial ectoderm, regardless of their original similarity, each follows a totally different line of development and differentiation so as to become structurally and functionally unlike in the adult condition. This **original similarity and adult divergence** should be noted throughout embryological and comparative studies.

In the myelencephalic portion of the brain, the neuromeres have lost their dorsal constrictions, though they can still be seen on the lateral and ventral surfaces, while the whole cord has thickened. This thickening constricts the lumen so that it is quite slit-like at this time. The neural tube has closed completely at both anterior and posterior ends at this period.

It will be remembered that the neural or medullary plates have formed, and their lateral folds have begun to unite to form the neural groove. This union has now been completed. The ectoderm, dorsal to the groove, has again become continuous, leaving a slight area between neural groove and superficial ectoderm.

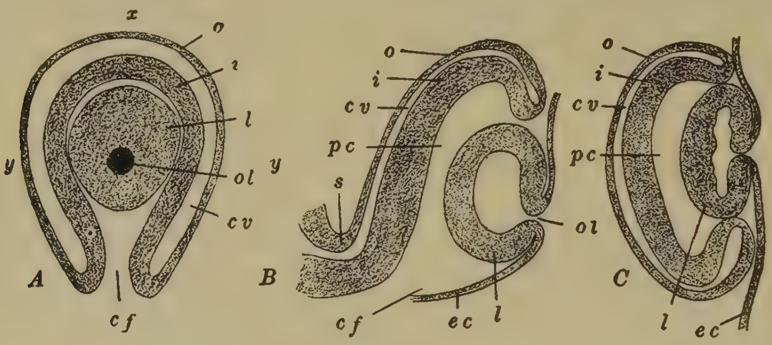


Fig. 289.

Diagrams of sections through the eye of the chick embryo at the end of the second day. The dorsal margin is toward the top of the page in *A* and *B*. *A*. Eye as viewed directly. *B*. Vertical section through the line *x-cf*, in *A*. *C*. Horizontal section through the line *y-y*, in *A*. *cf*. Choroid fissure; *cv*, cavity of primary optic vesicle; *ec*, superficial ectoderm of head; *i*, inner or retinal layer of optic cup; *l*, lens; *o*, outer or pigmented layer of optic cup; *ol*, opening of lens sac from surface of head; *pc*, posterior chamber of eye; *s*, optic stalk, continuous with the floor and lateral wall of the diencephalon. (From Lillie "Development of the Chick," by permission of Henry Holt & Co., Publishers.)

It will also be remembered that there are small groups of cells on each side of the midline lying within this area which we called **neural crests**, to distinguish them from the neural folds with which they were in close connection.

The two crests lying on each side of the midline fuse for a time, but because they began as two separate groups, they again become separate in a short time. They also form a sort of column on each side of the midline, running along the long axis of the embryo, but soon they segment and become the **dorsal root ganglia** or **sensory ganglia** of the spinal nerves (Fig. 290). As the segmented portions of these neural crests also extend into the head region, they there give rise to the ganglia of the **sensory cranial nerves.**

THE DIGESTIVE TRACT

At the period we are describing, the fore-gut has extended from the anterior intestinal portal as its posterior limit to the infundibulum as its anterior limit. It is divided into a **pharyngeal portion,** lying ventral to the myelencephalon and encircled by aortic arches, and an **oesophageal portion,** lying posterior to the pharyngeal with a much smaller lumen than the pharynx.

At this time there is an outpushing of the ventral portion of the pharynx and an inpushing from the ectoderm close to this region, which will soon meet and form the mouth-opening. The ectodermal inpushing is known as the **stomodaeum** and the thin layer of tissue between the inpushing and outpushing which is later to break through to complete the mouth-opening is called the **oral plate.** (Fig. 301, I, Seessel's pocket.) It is this oral plate region in the adult which separates the oral cavity from the pharynx.

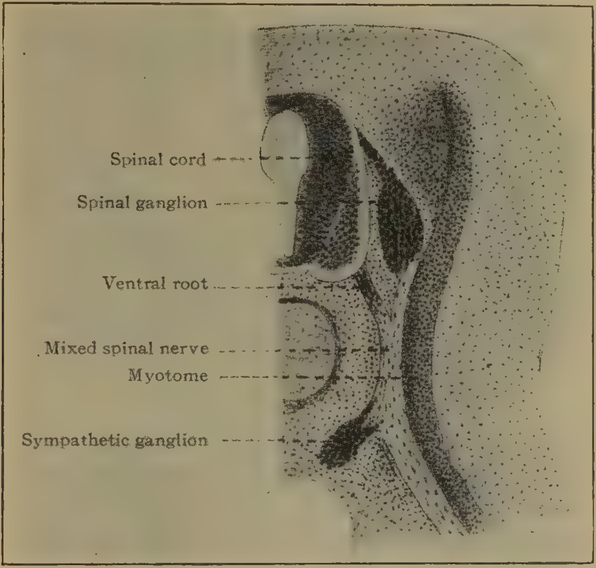


Fig. 290.

Developing nerve roots in a chick embryo of 4½ days. (After Neumayer.)

The fore-gut extends into the head region cephalad to the stomodaeum, and this portion is called the **pre-oral gut.** This pre-oral gut, however, disappears shortly after the oral plate breaks through, leaving only a small diverticulum which is then called **Seessel's pocket.**

The digestive tract has been lying close to the notochord up to this time, being separated from the notochord and the aortae by a broad thin layer of mesoderm. Now it begins to draw ventrad from this position, remaining attached, however, by the **mesentery,** a constantly narrowing band of tissue.

This mesentery is composed of mesoblast continuous with that which surrounds the entoderm of the digestive canal. The mesoblast consists of an undifferentiated middle layer (Fig. 291, b), in which blood

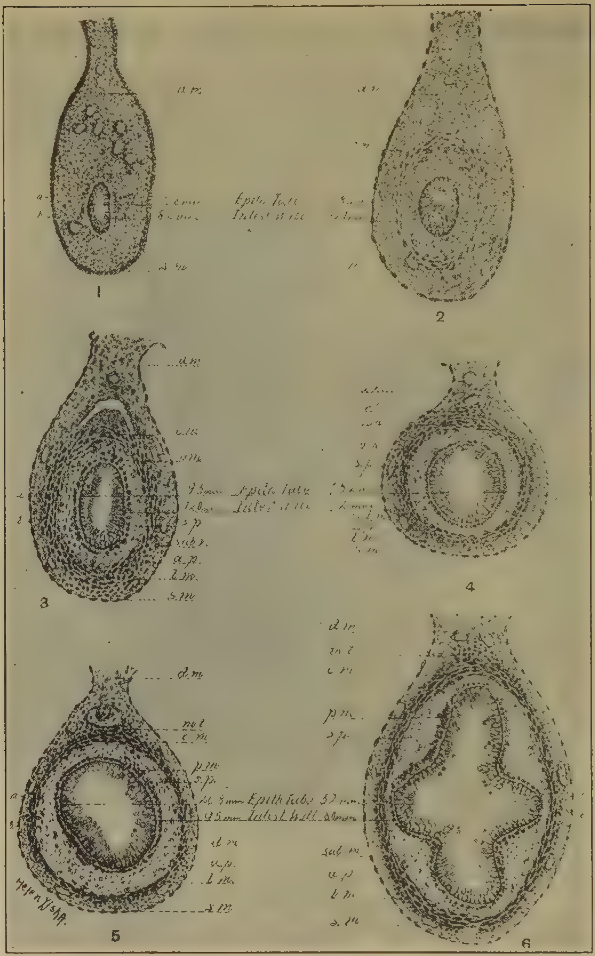


Fig. 291.

Development of Digestive Tract.

1 Transverse section of descending colon 10-mm. pig.
2 Transverse section of descending colon 14-mm. pig.
3 Transverse section of descending colon 20-mm. pig.
4 Transverse section of descending colon 25-mm. pig.
5 Transverse section of descending colon 31-mm. pig.
6 Transverse section of descending colon 46-mm. pig.

ABBREVIATIONS.

a., serosa.
b., undifferentiated middle layer.
dm., dorsal mesentery.
cm., inner circular smooth-muscle layer.
lm., outer longitudinal smooth-muscle layer.
mt., mesenteric taenia muscle band.
sp., Meissner's plexus (submucous.)
ap., Auerbach's plexus (intermuscular.)
sm., serosa.
subm., submucosa.
p.m., primordial mucosae cells.

N. B.—Note especially rapid increase in width of epithelial tube and the absolute decrease in thickness of mesenchymal wall due to tension stresses elicited by the growth of the former. (Eben J. Carey in The Anatomical Record, Vol, 19. No. 4.)

vessels are developed later, and a superficial layer (Fig. 291, a), of epithelium, continuous with the epithelial lining of the peritoneal cavity. The withdrawal of the anterior part of the fore-gut from the notochord is slight, as little or no mesentery is developed in that region.

It is interesting to note here that the oesophagus has its lumen closed for almost its entire length during the sixth day, only to reopen from the posterior region anteriorly again in about two days by the epithelial tube growing rapidly. This latter grows in a circular direction on account of the outer pressure.

The portion of the intestinal tract immediately posterior to the oesophagus becomes dilated on this day to form the stomach. This is followed posteriorly with a short region recognized as the duodenum because the beginnings of the liver and pancreas can be observed. Mesenchymal cells gather about the oesophagus and stomach from which their muscular and connective tissue coats will be derived.

There will be seen a small pitting in of the ectoderm to meet the underlying entoderm where the anal opening is to appear. However, this posterior opening does not open into the digestive tract until about the fifteenth day of incubation. The indenture which is to become the anal opening is called the **proctodaeum.**

The digestive tract is almost straight until the sixth day, when the various loops form and the gizzard develops as a thick-walled outgrowth from the end of the stomach.

THE LUNGS

Two small hollow outgrowths from the ventral side of the oesophagus near its anterior end are seen on this day, the oesophagus itself becoming constricted at the point of outgrowth.

These constrictions form two divisions, the more dorsal being the oesophagus and the ventral portion the **trachea.** At the point where oesophagus and tracheae are continuous, the **glottis** will be formed.

The trachea grows caudad and bifurcates to form pairs of **lung-buds.** These lung-buds extend outward into the surrounding mesenchyme lying on either side of the midline. The splanchnic mesoderm is pushed ahead of the growing lung-buds until it covers them and forms their outer investment layer, or pleural covering. The entoderm of the intestinal tract from which the trachea evaginated, forms the entire lining of trachea, bronchi, and all air-chambers in the adult lungs. The connective tissue stroma of the

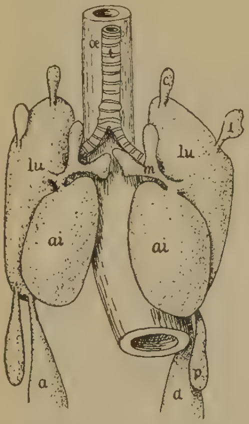


Fig. 292.

Ventral view of lungs and air-sacs of 12 day chick embryo. *ai*, anterior intermediate sac; *a*, abdominal sac; *c*, cervical sac; *l*, lateral part of interclavicular sac; *lu*, lung; *m*, mesial part of interclavicular sac; *oe*, oesophagus; *p*, posterior sac; *t*, trachea. (From Kingsley after Locy and Larsell.)

lungs, however, is derived from the mesenchyme surrounding the lung-buds.

In the chick and all birds, there is a characteristic thin-walled, sac-like outgrowth from the hinder edges of the lungs forming the air-sacs (Fig. 292). These do not appear until about the eighth day.

THE LIVER

The liver arises as a ventral diverticulum from the duodenum. It can be seen for a short time on the lip of the anterior intestinal portal growing cephalad toward the fork where the omphalomesentric veins enter the sinus venosus. The liver grows out as a series of cords pushing the splanchnic mesoderm ahead of it as its investing layer.

The liver evagination as it forms, retains its opening into the duodenum (Fig. 293), which later differentiates somewhat to become the common bile duct, the hepatic and cystic ducts, as well as the gall bladder. Cellular cords bud off from the diverticulum and become the hepatic tubules which have secretory functions.

As the intestinal portal moves caudad when the fore-gut lengthens, the proximal portions of the omphalomesenteric veins come together and fuse in midline. The fusion extends caudad nearly to the level of the yolk-stalk, beyond which they still remain separate. The liver now surrounds the fused portion of the omphalomesenteric veins.

It will be noticed, therefore, that the yolk materials

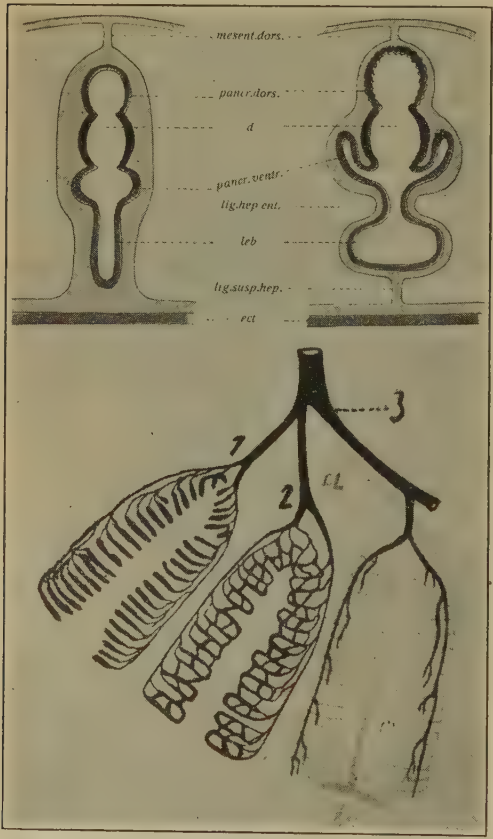


Fig. 293.

Two upper cuts are diagrams to show the development of the liver, pancreas, and hepatic ligaments. *d*, intestine; *ect*, ectoderm; *leb*, liver anlage; *lig.hep.ent.*, ligamentum hepato-entericum; *lig.susp.hep;* ventral mesentery or ligamentum suspensorum of the liver; *mesent. dors.*, dorsal mesentery; *pancr. dors.* and *pancr. ventr.*, dorsal and ventral pancreas. (After Schmikewitsch.)

Lower cut is a diagram to show the development of the liver. Lobule 1 shows the principal parts of the gall capillaries; Lobule 2, shows the anastomoses of these gall capillaries; in Lobule 3, only the efferent bile capillaries are shown, together with the arterial and venous capillaries. *a*, arteries; *b*, veins. (After Stohr.)

must already at this early period pass directly into and through the liver. If this is remembered, it will make the adult portal circulation the better understood.

THE PANCREAS

The pancreas arises as three diverticula from the duodenum at the approximate level of the liver diverticulum. There are three pancreatic buds, one medial, lying dorsal to the duodenum, and a pair of ventro-lateral buds.

The median bud appears at about seventy-two hours, while the two ventro-lateral buds can be seen at the end of the fourth day. The dorsal bud arises directly opposite the liver, and grows into the dorsal mesentery, while the ventro-lateral buds arise at the point where the liver connects with the intestine, so that both the liver duct and the ventral pancreatic duct open into the duodenum by a common duct called the **ductus choledochus.** Cellular cords grow into masses from the three buds, fusing into one glandular mass with two ducts remaining, although sometimes all three remain.

THE THYROID GLAND (Fig. 294)

This arises as a median diverticulum from the floor of the pharynx at the level of the second pair of gill pouches. By the close of the fourth day, the solid, rod-like diverticulum lying in a longitudinal position under the floor of the pharynx has become saccular, remaining connected with the point of origin as the **thyro-glossal duct opening** at the root of the tongue. In mammals, there are additional evaginations at the lateral region of the fourth gill pouch. By the sixth day, the thyroid body in the chick becomes bi-lobed, the lobes sending out cords of tissue which become hollowed out to form the regular adult thyroid tissue. The gland then shifts backward and becomes surrounded with a sheath of vascular connective tissue.

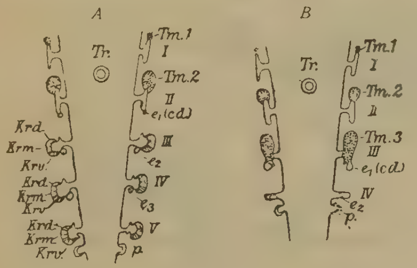


Fig. 294.

Diagrams to show the development of the derivatives of the digestive tract in the branchial region. A, *Anura*, B, *lizard*. *cd*, carotid gland; e^1-e^3, epithelial bodies; *Krd*, *Krm*, *Krv*, dorsal, mid, and ventral remains of the axial portions of the gill pouches; *p*, postbranchial bodies; *Tm*1=3, Thymus anlage; *Tr*, Thyroid gland; I-V, Gill slits (After Maurer.)

THE THYMUS GLAND

(Fig. 294)

This organ arises from the posterior faces of the third and fourth gill pouches after the fourth day of incubation. While the organ is originally epithelial in character, there is soon an ingrowth of mesenchyme and the thymus then becomes chiefly lymphoid in structure.

THE VISCERAL CLEFTS AND VISCERAL ARCHES

Different parts of the embryo grow at different rates of speed, and while the heart was formed directly under the anterior end of the digestive tract on the second day, on the third day the heart has shifted its position so far posteriorly that there is a distinct space between it and the head proper. This space we may call the neck or **pharynx.**

It is in this region that the mesoderm has not divided into the two layers—the somatic and splanchnic. We therefore still have a sort of sheet consisting of the three primitive layers of ectoderm, mesoderm, and entoderm, extending outward from the embryo.

The entodermal lining of this neck region becomes pushed out into four narrow pockets (Fig. 295, A), called the **visceral** or **gill pouches,** during the latter part of the second or the early part of the third day. These meet with ectodermal depressions formed as furrows which grow inward to meet the gill pouches. The thin wall between the outpushings and the ectodermal inpushings breaks through in the lower forms, such as in fish and amphibia, and there remains open throughout life, but in the chick the opening is seen in the first three pairs during the first three or four days. It remains open for about two days. These openings, or places where openings usually occur, are known variously as **visceral clefts, gill clefts,** or **branchial clefts.**

As the neck is considerably curved, these clefts do not lie parallel to each other, but converge toward the ventral part of the neck. The fourth cleft never opens in the chick.

Numbering and naming of these clefts begins with the most anterior and continues caudad.

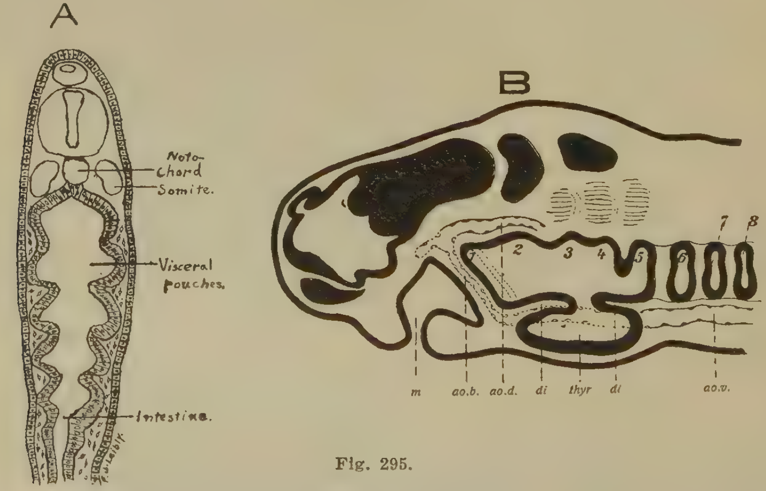


Fig. 295.

A, Horizontal, and *B* longitudinal section through the head region of *Ammocoetes* (larval stage of lamprey.) *ao.b.*, anterior aortic arch; *ao.d.*, dorsal aorta; *ao.v.*, ventral aorta; *di*, invagination which separates the anlage of the thyroid gland from the digestive tract; *m*, anlage of mouth; *thyr*, thyroid anlage; 1, ciliated gill region which probably becomes the spiracle; 2-8, gill pouches. (*A*, after Vialleton; *B*, after Dohrn.)

The first one is called the **hyomandibular cleft,** while the remaining ones are known respectively as the II, III, and IV **gill clefts.**

Between these clefts, as well as immediately anterior and posterior to them, there is a pair of thickened regions, each pair of which meets ventrally in the midline and merges with its mate from the opposite side of the body. These thicknesses are called **visceral arches, gill arches,** or **branchial arches,** also numbered from the anterior end, caudad. The first is called the **mandibular,** the second the **hyoid,** and from here caudad the III, IV, and V.

The hyomandibular cleft lies between the mandibular and hyoid folds or arches.

It is well at this point to anticipate a little as to what is to become of these structures later (Fig. 296).

All the clefts close, with the exception of the hyomandibular. This, too, begins closing at the end farthest from the pharyngeal opening, but retains the opening into the pharynx. The unclosed end itself becomes the **tympanic cavity,** while the remaining portion of the cleft becomes the **Eustachian tube.**

The external auditory meatus is formed by a depression in the surface ectoderm opposite the position of the tympanic cavity. The outer end of the closed hyomandibular cleft thus lies between the tympanic cavity and the external auditory meatus, the tissue formed by the closure of the cleft forming the tympanic membrane.

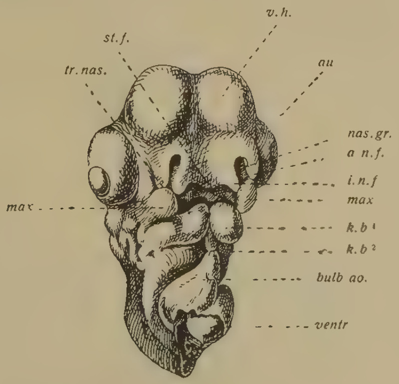


Fig. 296.

Head of a 5½ day chick embryo. *a.n.f.*, lateral nasal process; *au*, eye; *bulb.ao.*, bulbus aortae; *i.n.f.*, inner nasal process; *k.b.*^{1} and *k.b.*^{2} mandibular and hyoid arches; *max*, upper process of the mandibular arch; *nas.gr.*, nasal groove; *st.f.*, frontal process; *tr.nas.*, tear-duct running to nasal cavity; *ventr.*, ventricle; *v.h.*, forebrain. (After Duval.)

The most posterior two gill arches or folds entirely disappear in adult stages of the chick.

The pair of mandibular arches grow toward each other on the ventral side and fuse to form the basis of the **mandible,** or lower jaw. From the dorsal end of each mandibular arch and at their anterior edge, a small branch grows downward and forward during the fourth and fifth days. Such branch or branches are called **maxillary processes.** There is a triangular median process growing toward these maxillary processes from the front of the head, known as the **fronto-nasal** process. The maxillary processes form the upper jaw or the maxillary bones. The maxillary processes do not fuse with each other, but to each side of the fronto-nasal process. When this union does not become complete, the well-known abnormality of **hare-lip** results.

The formation of clefts and arches may be understood the better by the following illustration from Professor Reese:

With the hands in front of the body (the palmar aspect of each hand directed mesiad), and pointed downward, "bring the tips of the fingers together, the fingers of each hand being slightly separated. The thumbs should, at first, be closely pressed against the forefingers, and should be considered as fused with them. If the fingers and hands are slightly bent, there will be a space between the two hands that may be taken to represent the pharynx of the chick, while the four fingers will represent the first four gill arches, and the spaces between the fingers will represent the first three gill clefts. The closure of the visceral clefts may be represented by bringing the fingers of each hand together. The forefingers, which should, in reality, be the only ones which actually meet in the midventral line, will represent the mandibular arch, forming the lower half of the mouth. The formation of the maxillary arch, by processes budded out from the upper ends of the mandibular arch, may be represented by separating the thumbs from the forefingers, and pointing them toward each other without letting them come in contact; the triangular space between the thumbs, thus held, being fulfilled in the imagination by the fronto-nasal process. The angles between the thumbs and forefingers will represent the angles of the mouth. Of course, to make the comparison more striking, there should be one more finger to represent the hindermost arch and cleft, but as the hinder arches and clefts form no part of the adult chick, this omission is of little importance."

THE CIRCULATORY SYSTEM (Fig. 297)

As has been stated, there are already two or three pairs of aortic arches present, by which blood is carried from the bulbus arteriosus around the pharynx to the dorsal aorta. It will be noted that the first aortic arch lies in the first (mandibular gill arch), the second in the hyoid fold, and so on, each bearing a distinct relation to the correspondingly numbered gill-fold.

The heart, which it will be remembered is attached only at the cephalic and caudal ends, is growing rapidly and twisting upon itself. The venous or atrial side is the more stationary. This side, originally, lay caudal to the arterial or conus end of the heart, but in the twisting, the conus end comes to lie caudal to the sinus or venous end, a position that the higher vertebrates all retain in the adult stage. In fishes, the atrial region of the heart remains caudal to the ventricular portion even in the adults.

The point where the two vitelline veins meet to empty into the heart becomes pushed farther and farther caudad, so that the two veins unite and form a common opening into the heart. All blood from the vascular area to the heart passes through this single common tube, though in a short time the right vein will dwindle away and disappear. The tube is then an opening for the left vitelline vein only. This common tube-like entry into the heart is called the **meatus venosus**; the portion nearest the heart is the **sinus venosus**, and the portion lying more distal, the **ductus venosus**.

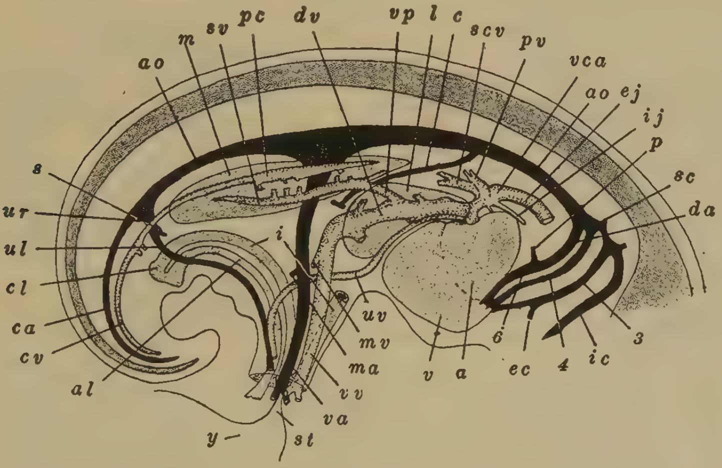


Fig. 297.

Diagrammatic lateral view of the chief embryonic blood-vessels of the chick, during the sixth day. *a*, Auricle; *al*, allantoic stalk; *ao*, dorsal aorta; *c*, cœliac artery; *ca*, caudal artery; *cl*, cloaca; *cv*, caudal vein; *da*, ductus arteriosus; *dv*, ductus venosus; *ec*, external carotid artery; *ej*, external jugular vein; *i*, intestine; *ic*, internal carotid artery; *ij*, internal jugular vein; *l*, liver; *m*, mesonephros; *ma*, mesenteric artery; *mv*, mesenteric vein; *p*, pulmonary artery; *pc*, posterior cardinal vein; *pv*, pulmonary vein; *s*, sciatic artery; *sc*, subclavian artery; *scv*, subclavian vein; *st*, yolk-stalk; *sv*, subcardinal vein; *ul*, left umbilical artery; *ur*, right umbilical artery; *uv*, left umbilical vein; *v*, ventricle; *va*, vitelline artery; *vca*, anterior vena cava (anterior cardinal vein); *vp*, posterior vena cava; *vv*, vitelline vein; *y*, yolk-sac; 3, 4, 6, third, fourth, and sixth aortic arches. (From Lillie's "Development of the Chick," by permission of Henry Holt & Co., Publishers.)

The dorsal aorta gives off numerous branches supplying various portions of the body of the embryo, the blood being returned by two large veins on each side of the body. That from the anterior part of the embryo being carried through the anterior cardinal veins and that from the posterior part of the body being carried by the posterior cardinal veins, the anterior and posterior cardinals then unite into a common vein before emptying into the sinus venosus, and this common vein is called the **duct of Cuvier**.

XXXVI.

THE DIFFERENTIATION OF THE SOMITES

The somites have already been described as almost solid triangular blocks of cells derived from the dorsal mesoderm. There is a tiny opening in the center running horizontally through the somite. Oftentimes the opening cannot be seen at all. This opening is called the **myocoele.**

As the embryo continues to increase in size, the triangular block becomes more or less circular and there are two layers of cells, an outer epithelial layer and an inner portion (Fig. 298). The inner portion has its cells irregularly arranged.

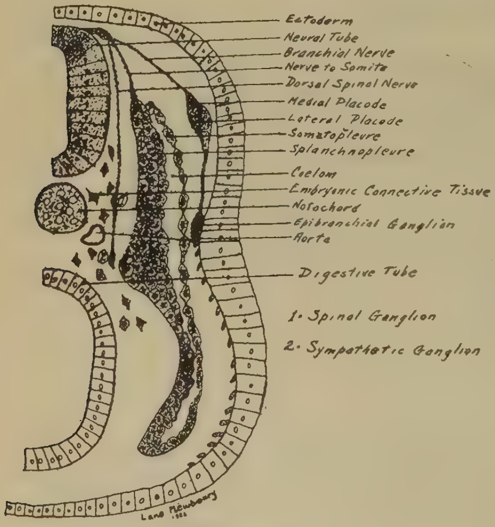


Fig. 298.

Diagram of Myotome and Nerve Development. The more dorsal portion of the somatopleure is known as the dermatome while the dorsal portion of the splanchnopleure lying closest to the dermatome forms the sclerotome.

It is this ill-defined group of cells which is known as the **sclerotome.** The cells are mesenchymal.

The sclerotomes of each side now grow still farther toward the notochord and surround it. Later they develop into the vertebrae.

The dorsal portion of the outer cell mass whose more medial portion became the sclerotome, has retained its definite outlines and epithelial characteristics. This portion, now called the **dermatome**, is to become the deeper layer of the integument. It is important to remember at this point that the ectoderm gives rise to the epithelial layer of the integument only.

The portion of the cell mass which lies medial and slightly ventral to the dermatome is called the **myotome.** The myocoele now lies between the dermatome and the myotome. It is from the myotome that the entire skeletal musculature is developed by the ventral walls of the myotome becoming converted into longitudinal muscle fibers. These bands of fibres then remain divided into blocks which correspond to the original somites. Here again we have a metameric arrangement of muscles in the embryo of the chick which corresponds to the segmental arrangement of muscles in the adult fish.

The outer portion of the myotome gives rise to the muscles of the neck and trunk, the muscles of the appendages arising independently of the myotomes.

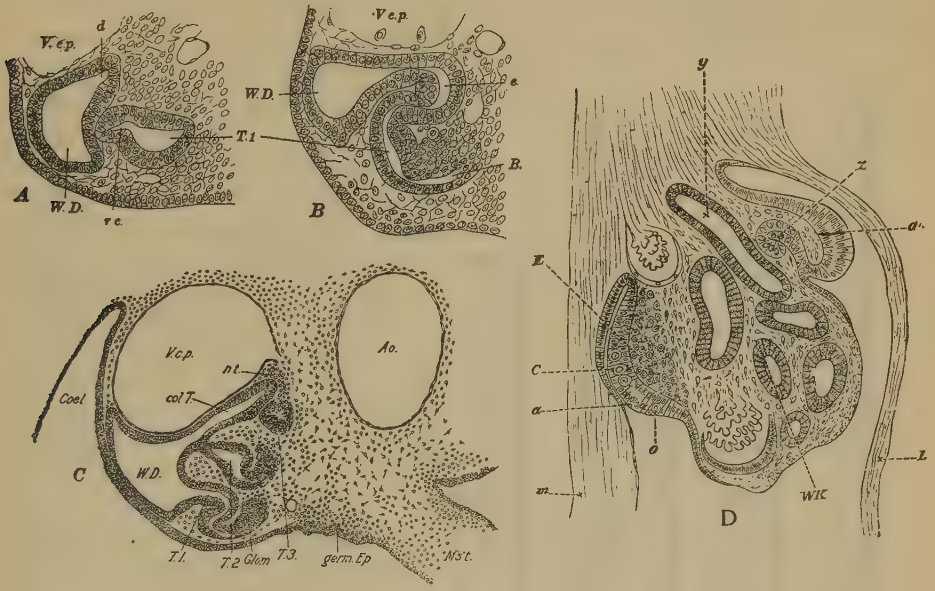


Fig. 299.

The development of the mesonephros. *A*, *B*. Transverse sections through the mesonephric tubules of the duck embryo with forty-five pairs of somites. After Schreiner. *C*. Transverse section through the middle of the mesonephros of a chick of ninety-six hours. From Lillie (Development of the Chick). *Ao.*, Dorsal aorta; *B.*, rudiment of Bowman's capsule; *c.*, collecting duct; *Cœl.*, cœlom; *Col. T.*, collecting tubule; *d.*, dorsal outgrowth of the Wolffian duct; *Glom.*, glomerulus; *germ. Ep.*, germinal epithelium; *M's't.*, mesentery; *n.t.*, nephrogenous tissue; *r.*, rudiment of conducting portion of primary tubule; *T.* 1, 2, 3, primary, secondary, and tertiary mesonephric tubules; *V.c.p.*, posterior cardinal vein; *W.D.*, Wolffian duct. *D*, Cross section through the head kidney in the region of the gonads of a 4 day chick embryo. *a*, germinal epithelium showing the primary germ-cells *c* and *o*; *a*, portion of the peritoneal epithelium which forms the Mullerian duct; *E*, the tissue immediately surrounding the germ cells which forms the stroma of the gonads later; *L*, Somatopleure; *m*, mesentery; *WK*, Pronephros; *y*, Wolffian duct; *z*, Mullerian duct. (After Waldeyer and O. Hertwig.)

THE EXCRETORY SYSTEM

It is on the third day that the intermediate cell mass—the **mesomere** (Fig. 268, mm)—lying between the somite proper and the point where the mesoderm splits into somatic and splanchnic layers, becomes very prominent, being covered with sharply defined epithelial cells (Fig. 299).

It is of great importance for one's future study of embryology as well as for the study of comparative anatomy that the development of the excretory system be thoroughly understood.

It is this intermediate cell mass or mesomere, now called the **nephrotome**, which is to develop into both urinary and reproductive systems.

The Wolffian duct has already been mentioned. The embryonic kidney in the chick is called the **Wolffian body** or **mesonephros.** This embryonic kidney ceases to function very soon after hatching, and is then replaced by the **metanephros.**

One of the lowest forms of a **chordate** (an animal which possesses a notochord), is the small fish-like **amphioxus** or **lanceolatus.** In this animal a primitive form of excretory system develops and persists throughout the adult life of the animal. It is called a **pronephros,** or **head kidney.** This structure develops in the frog and other amphibia during the embryonic period, but it is followed by the **mesonephros** or **Wolffian body,** which becomes the permanent kidney of the amphibian, while in the chick, as in all amniotes, the mesonephros serves as the embryonal kidney, which is then followed by the development of a **metanephros** or permanent amniote kidney. (Fig. 300.)

Notwithstanding the type of these three kidneys which an animal may possess in adult life, all of the higher animal forms develop what the immediately lower animal form possesses, plus the next succeeding type of pronephros, mesonephros, or metanephros.

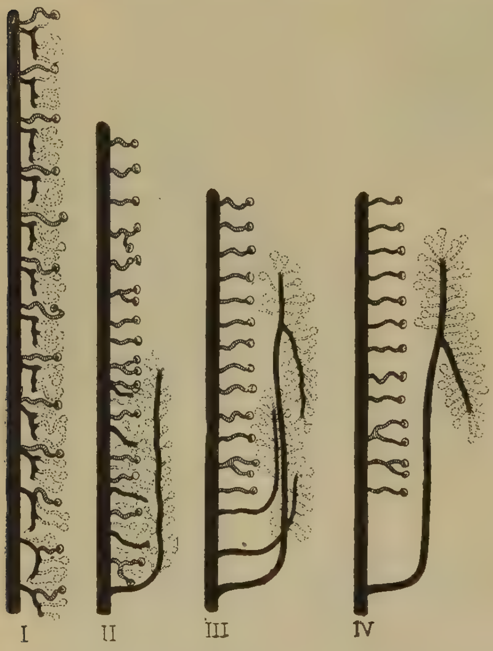


Fig. 300.

Schematic arrangement to show relationship of metanephros and mesonephros. *I,* in Gymnophiona (tropical amphibians without tails or legs). *II,* in advanced chick embryo. *III,* one type of its appearance in man. *IV,* in rabbit. The Wolffian duct and ureters are black. The canaliculae of the mesonephros are hatched. The canaliculae of the metanephros are dotted. (After Felix.)

Amphioxus therefore has the pronephros as its permanent kidney, amphibians have the pronephros as a sort of embryonic kidney with the mesonephros in the adult form, while all higher types of animals have a pronephros (which just appears and degenerates during the early embryonic period) with a mesonephros acting as an embryonic organ of excretion, and then, later, from the caudal region of the mesonephric duct the adult permanent kidney or metanephros develops.

To obtain a clear and accurate view of the functional and structural relations of the three kidney-forms, it is important to summarize the nephridial theory here.

Theoretically, it appears that the waste matter containing nitrogen which is elaborated in the primitive liver and collected in the coelom, together with the coelomic fluid itself, passes outward through the nephrostomes and tubules in each segment. In higher forms all the parts are more differentiated and some of the segmentation is lost.

Figure 168 gives a clear understanding of the earthworm's segmented excretory system which represents the pronephridic type of kidney.

Such a primitive type of nephridia, if completely developed, may be described as follows: At the proximal end of the tubule, a ciliated funnel, the **nephrostome,** opens into the coelom. The cilia may continue into the tubule to produce a current which will carry the coelomic fluid into and through the tubule. The tubule expands into a **Malpighian** or **renal corpuscle.** This corpuscle consists of a vesicle known as **Bowman's capsule,** one side of which projects into the other, so that the cavity is nearly filled. The inturned portion is the **glomerulus,** consisting of a network of capillary blood vessels, supplied by an artery and drained by a vein. Beyond the Malpighian corpuscle the tubule becomes convoluted, while its cells become glandular. The first convoluted tubule is followed by a straightened portion forming a simple U shape. The arms of the U form the ascending and descending limbs. The entire U is called **Henle's loop.** Then follows a second convoluted tubule which passes by means of a short connecting tubule into the non-glandular **collecting tubule.** Other groups of similar-formed excretory units enter this same collecting tubule, which then leads into a urinary duct through which the waste matter is carried out of the body.

Various parts of the complete system just described may be missing in different groups of animals. For example, in **Amniotes,** the nephrostomes are never formed, though they are in **Ichthyopsida.**

In the pronephros, the Malpighian corpuscle is quite rudimentary and often entirely lacking, and there is also no differentiation into convoluted tubules and Henle's loop.

The renal corpuscles form a sort of filtering apparatus by which water is passed from the blood-vessels of the glomerulus into the tubules near their beginning, which liquid thus serves to carry out the urea, uric acid, etc., which has been secreted by the glandular portions of the walls of the tubules.

A varying number of nephrotomes form in different animal forms, and so also a varying number of nephrostomes form. Figure 300 will give the student a general idea of how mesonephros, and metanephros, follow each other and just what their relations are.

The tiny tubules must not, however, be confused with the ducts. The ducts represent the **collecting tubule** described above.

The pronephric tubules grow first and then join the pronephric ducts. Later the mesonephric tubules grow caudad to the pronephric tubules and join the same ducts. The original pronephric tubules then degenerate, so that now the ducts which were originally called pronephric become the mesonephric ducts.

In the real kidney, or metanephros, the tubules do not grow toward the mesonephric ducts, but **from** these ducts. They grow headward and laterad and ultimately connect with the tubules of the mesonephros, after which the mesonephros itself degenerates with the exception of the Wolffian or mesonephric ducts, which in the male become the tubules through which the sperm pass.

With this in mind, the excretory system of the chick can be studied with some understanding.

At about thirty-six hours, it will be remembered, the pronephric tubules were seen to arise from the nephrotome, one pair lateral to each somite from the fifth to the sixteenth. Each tubule arises as a solid bud of cells with the free ends growing dorsad, close to the posterior cardinal veins. The distal end of each tubule is bent caudad later, until it reaches the tubule directly posterior to it. Thus is formed a continuous cord of cells which is to become the pronephric duct. These ducts continue to extend caudad beyond the region where the tubules were formed, and soon develop a lumen. The ducts ultimately reach the cloaca, extending ventrally and opening into it.

The best way to study a series of cross sections is to begin caudad and observe them serially toward the head, because the posterior portions are not so well developed as are the anterior.

The pronephros (Figs. 285 and 299, D) varies in its development, although it usually can be noted in from the fifth to the fifteenth or sixteenth somite. Typically it develops from the tenth to fifteenth, inclusive. No duct is formed anterior to the tenth somite, the pronephric buds in that region disappearing by the end of the second day.

Mesonephric tubules (Fig. 299, A, B, C), develop in all segments from the thirteenth or fourteenth to the thirtieth, so that the most anterior mesonephric tubules develop in the same segments where the pronephric tubules also developed, although it is only posterior to the twentieth segment that the mesonephros develops **typically.**

The mesonephric tubules, which are to connect with the ducts, are developed from radially arranged cell masses lying ventral and medial to the ducts. The most anterior of these tubules acquire a lumen by the time the ducts have developed their lumen. These tubules grow toward and connect with the duct. Later they remain as isolated vesicles. The grouping of the mesonephric tubules constitutes the **mesonephros** or **Wolffian body.** Some of the more cephalad mesonephric tubules seem to develop nephrostomes opening into the coelom.

The tubules themselves, having formed separately from the ducts and then grown outward and connected with them, have had their outward ends develop a cluster of closely packed cells which lies in close relationship to the dorsal aorta. This cluster becomes the glomeruli.

In fact, by the fifth day, circulation has already been established in the glomeruli, and from then until the eleventh day, the mesonephros is at the height of its functional activity. Then the metanephros takes its place.

The pronephric tubules which attain even a degree of completeness lie in the tenth to fifteenth somites. It is interesting to observe that when these tubules begin to degenerate, the glomeruli begin to form at the points of the tubules, close to the coelom and actually project into the coelom. These bud-like structures are extremely variable, both as to number and degree of development. They even develop differently on both sides of the chick. They appear to be best developed on the third and fourth days. It is for reasons such as the ones mentioned above that former writers insisted that in the chick the pronephros really developed **later than** the mesonephros.

XXXVII.

THE DEVELOPMENT OF THE FOURTH DAY

On opening an egg which has been incubated for four days, the great increase in size of the embryo is the most noticeable feature. The germinal membrane now covers almost one-half of the yolk, and the

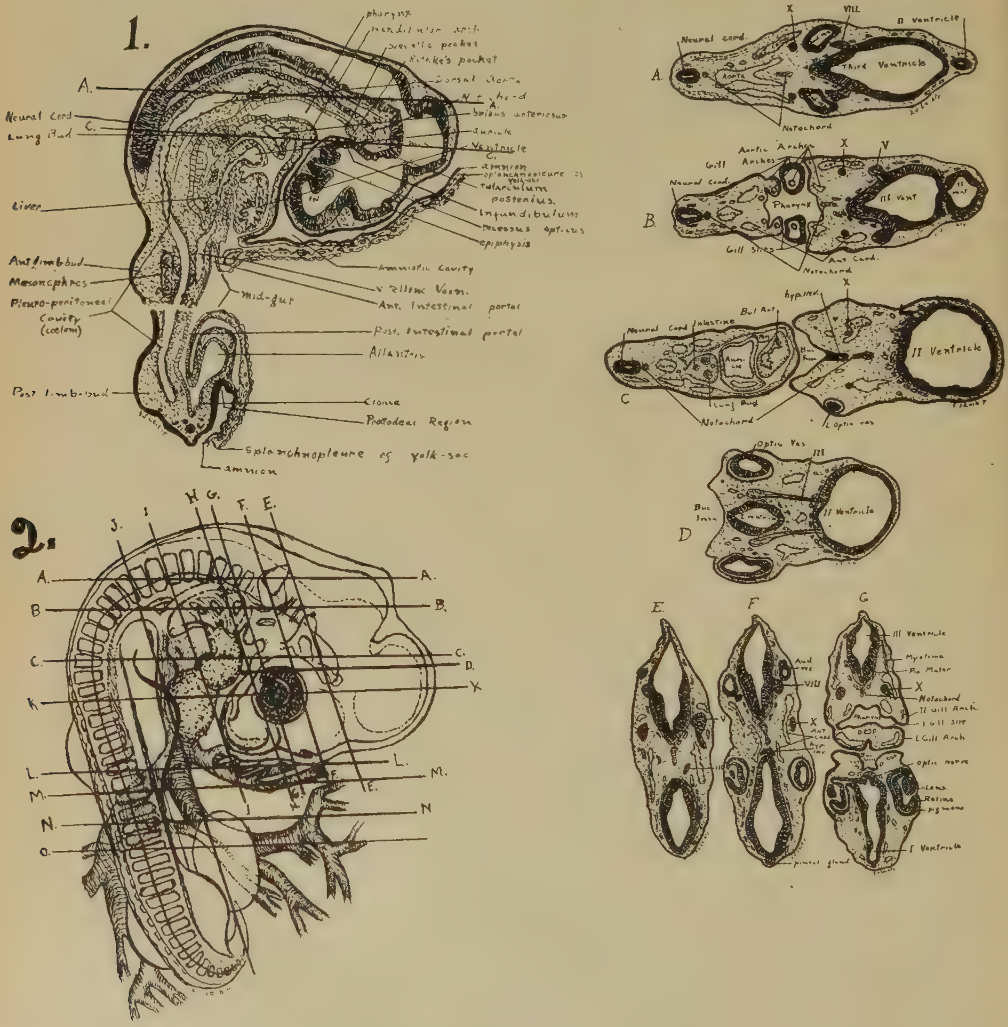


Fig. 301.

1, Median sagittal section of 82 hour chick embryo. 2. Whole mount to show regions from which A to O are cut. Sections A=A—A; B=B—B; etc. (Redrawn from Duval.)

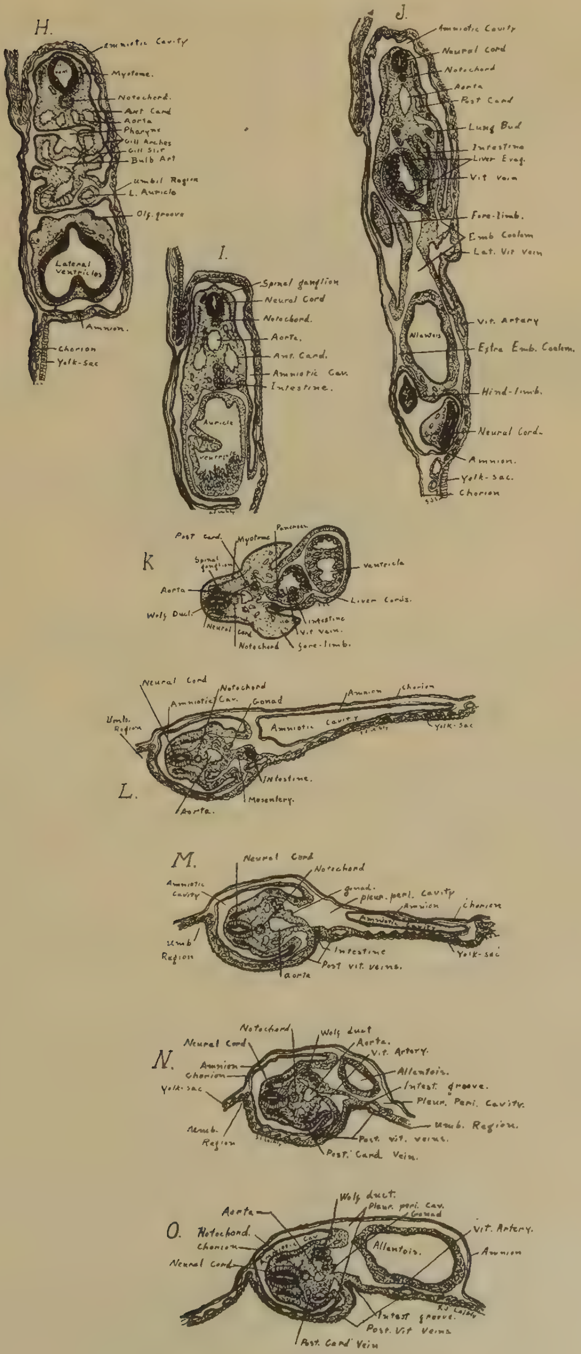

H.
Amniotic Cavity
Myotome.
Notochord.
Ant Card
Aorta
Pharynx
Gill Arches
Gill Slit
Bulb Art
Umbil Region
L. Auricle
Olf. groove
Lateral ventricles
Amnion.
Chorion
Yolk-Sac
I.
Spinal ganglion
Neural Cord
Notochord.
Aorta.
Ant. Card.
Amniotic Cav.
Intestine.
Auricle
ventricle
J.
Amniotic Cavity
Neural cord
Notochord
Aorta
Post Card
Lung Bud
Intestine
Liver Evag.
Vit Vein
Fore-limb.
Emb Coelom
Lat. Vit Vein
Vit. Artery
Allantois
Extra Emb. Coelom.
Hind-limb.
Neural Cord.
Amnion.
Yolk-sac.
Chorion
K
Post card.
Myotome
Pancreas
Spinal ganglion
Aorta
Wolf Duct.
Neural cord
Notochord
ventricle
Liver Cords.
intestine
Vit vein.
fore-limb.
L.
Neural Cord
Notochord
Amniotic Cav.
Gonad
Amnion
Chorion
Umb. Region
Amniotic cavity
Yolk-Sac
Intestine.
Mesentery.
Aorta.
M.
Neural Cord
Notochord
Amniotic Cavity
gonad.
pleur. peri. cavity
Amnion
chorion
Amniotic cavity
Umb Region
Intestine
Yolk-sac
Post vit. veins.
aorta
N.
Notochord
Wolf duct
Neural Cord
Aorta.
Vit. Artery.
Amnion
Chorion
Allantois.
Yolk-sac
Intest. groove.
Pleur. Peri. Cavity.
Umb. Region.
Umb. Region
Post. vit. veins.
Post. Card. Vein.
O.
Wolf duct.
Aorta
Pleur. peri. cav.
Gonad
Notochord.
Vit. Artery.
Chorion
Allantois.
Amnion
Neural Cord
Intest groove.
Post. Vit Veins
Post. Card Vein

Fig. 301.

vascular area is very prominent, although the sinus terminalis has already begun to diminish in distinctness.

The amnion covers the entire chick, but as there is as yet little fluid in the amniotic cavity, the amnion lies close to the embryo.

The splanchnic stalk forms a narrow tube connecting yolk-sac and mid-gut, but the somatic stalk has not kept even pace with the splanchnic, so that there is a ring-shaped space between the two through which space the allantois projects. The allantois is connected by a narrow stalk with the hind-gut just cephalad to the tail.

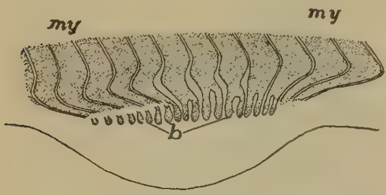


Fig. 302.

Appendage muscles being budded off from myotomes in the European Dogfish, *Pristiurus*. *b*, muscle buds; *my*, myotomes. (From Kingsley after Rabl.)

The cranial flexure increases to a considerable extent as does also the body flexure, so that the embryo now describes a half-circle.

The muscle plates are nearly vertical in position, extending almost to the point of separation of somatopleure and splanchnopleure, while just beyond this point of separation the somatopleure is raised to form a longitudinal ridge on each side, which is called the **Wolffian ridge.**

It is on this day also that the beginnings of the appendages, the wings and legs, can be seen as local swellings of the Wolffian ridge.

These arise (the wing-buds just posterior to the heart region, and the hind-limb-buds just anterior to the tail) as conical or triangular groups of mesoderm covered by ectoderm (Fig. 302). By the end of the day the wing-buds have become elongated and narrow, while the limb-buds are short and broad.

The embryo now lies on its left side, torsion being complete to the extent of ninety degrees.

It is on this day also that a fourth gill cleft appears. The gill arches become so thick now that one can scarcely see the aortic arches in any of them.

In the head region, the cephalic flexure presses the ventral surface of the head so tightly against the pharynx that the head and pharyngeal region must be removed and studied from their ventral aspects or little can be observed.

Figure 296 will show that the mandibular arch forms the more caudal boundary of the oral depression, while on each side, the arch forms an elevation, the maxillary processes, which grow mesiad and form the antero-lateral boundaries of the mouth opening.

The nasal pits form as hollow depressions in the ectoderm of the anterior part of the head overhanging the mouth region with U-shaped elevations surrounding them. The median limb is the **naso-medial process** and the lateral limb is the **naso-lateral process.** The two naso-medial processes grow toward the mouth and meet the maxillary processes which grow inward from each side. It is the fusion of these two naso-medial processes with each other in the midline and with the maxillary processes laterally that forms the upper jaw, the **maxilla.**

The lower jaw is formed by the fusion in the midline of the right and left portions of the mandibular arch.

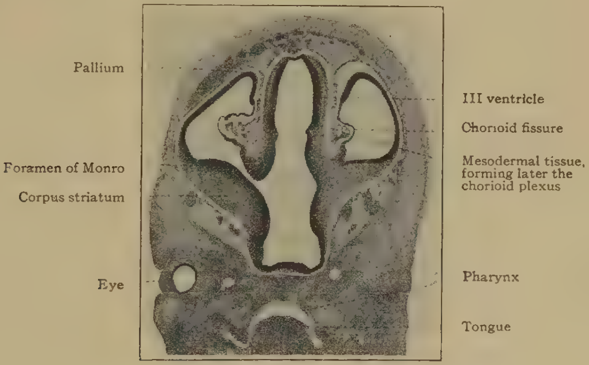


Fig. 303.

Transverse section through the forebrain of a 16 mm. human embryo (six to seven weeks) to show the relationship of the ventricles.

THE NERVOUS SYSTEM

Figures 282 and 288 show how the two lateral evaginations of the fore-brain stand in relation to the cephalic end of the central nervous system, and why it is that the ears come to lie on practically the same dorso-ventral level with the eyes, although they begin forming so far apart.

The development which brings this about has already been discussed. Here it is important for the student to observe that the two evaginations forming the telencephalic vesicles have an open space within them, known as the I and II ventricles, also called **lateral ventricles.** The portion between them is the III ventricle, which is later to become a mere connecting slit-like tube to connect the lateral and more posterior ventricles. The entire opening in the fore-brain is called the **telocoele,** that in the diencephalon the **diocoele,** that of the mesencephalon the **mesocoele** (later called the **aqueduct of Sylvius**), that of the metencephalon the **metacoele,** and that in the myelencephalon the **myelocoele.**

Figure 282 also shows that what was once the most anterior part of the fore-brain, i. e., the lamina terminalis, is no longer so, the lateral vesicles having extended further forward. The telencephalic vesicles become the cerebral hemispheres in the adult. These become so large that they cover the entire diencephalon and mesencephalon.

All discussion of the central nervous system in our future study of comparative anatomy will depend upon the student's thorough understanding of the development of the brain regions and vesicles as here discussed. Consequently, the various arbitrary lines used as demarcations must be carefully studied.

The division between telencephalon and diencephalon is the imaginary line drawn from the **velum transversum** to the **recessus opticus.** The velum is that slight extension marking the point where the primary fore-brain is to divide, while the recessus is that transverse furrow in the floor of the brain which leads directly into the lumina of the optic-stalks.

The Diencephalon: There is little change in this on the fourth day, except that the infundibular depression in the diencephalon has deepened, and lies close to Rathke's pocket (Fig. 301, I), with which it later fuses to form the **hypophysis.** Later the lateral walls of the diencephalon are to become thickened to form the **thalami.** As these thalami grow inward toward each other, they will cause the diocoele or third ventricle to become quite small. The anterior part of the roof of the diencephalon remains thin, and the blood-vessels grow downward into the diocoele as the **choroid plexus.**

The division between diencephalon and mesencephalon is an imaginary line drawn between the **tuberculum posterius** (a rounded elevation in the floor of the brain, of importance only as a landmark of this kind), and the internal ridge formed by the original dorsal constriction between the primary fore-brain and mid-brain.

The Mesencephalon: There is little change in this portion of the brain, though a little later, dorsal and lateral walls become thickened to form either the **optic lobes** or the **corpora quadrigemina.** Optic lobes and optic vesicles must not be confused, as these are two separate and distinct structures.

The floor of the mesencephalon thickens to form the **cerebral peduncles** of the adult, which serve as the main pathway for the fiber tracts which connect the cerebral hemispheres with the posterior part of the brain and spinal cord. The mesocoele becomes quite small by these various thickenings and is now called the **aqueduct of Sylvius.**

The Metencephalon: The metencephalon is separated from the mesencephalon by the original inter-neuromeric constrictions which arose early and marked off this portion of the brain. The caudal boundary is not well defined, though it is supposed to merge in the myelencephalon where the roof changes from its thickened state to the thinner condition observed more posteriorly. There is little change on the fourth day in this region, though later an extensive ingrowth of fiber tracts develops both on the ventral and lateral walls. These fiber tracts form the **pons** and the **cerebellar peduncles,** while the roof of the metencephalon enlarges and becomes the **cerebellum.**

The Myelencephalon: There is also little change in this region, but later the roof becomes thinner and blood-vessels push their way into the opening now called the fourth ventricle, as the **posterior choroid plexus,** while the ventral and side-walls become floor and lateral walls of the medulla.

THE GANGLIA OF THE CRANIAL NERVES (Fig. 282, B)

Along the neural crests already discussed, various ganglia are formed. The largest on the fourth day is known as the **Gasserian ganglion** of the **fifth cranial nerve.** (The fifth is also called the **trigeminal nerve.**) It lies ventral and lateral, as well as opposite to the most anterior neuromere of the myelencephalon. It forms the **sensory nerve fibers** which grow from the brain mesially and distally into the mouth and face region. This fifth cranial nerve is divided into three great branches: the **ophthalmic,** the **maxillary,** and the **mandibular.**

The first branch, the ophthalmic, can be seen on the fourth day extending toward the eye, while the other two are just beginning to grow toward the mouth angle.

Just anterior to the auditory vesicle a mass of neural-crest cells is developing into what is to become the **facial** or **seventh cranial nerve** and the **acoustic** or **eighth cranial nerve.** This cell mass divides on the fourth day to form the **geniculate ganglion** of the seventh and the **acoustic ganglion** of the eighth nerve.

Caudad to the auditory vesicle, the ganglion of the **glossopharyngeal** or ninth cranial nerve can be seen, and the ganglion of the vagus or tenth nerve may just be observed. The ninth can be seen in whole mounts, the tenth probably cannot.

THE SPINAL CORD

Throughout the spinal cord there is a compressed, slit-like lumen known as the **central canal.** Just as the ganglia of the cranial nerves make their appearance on the fourth day, so, too, do the spinal nerves.

It requires special methods of staining to study the growth of the nerve fibers from the **neuroblasts,** but the development of the spinal nerve roots can be studied in ordinarily stained slides.

It is important to understand that in the adult there will be two roots to each spinal nerve (Fig. 290), one **ventral,** which is **motor** in function, and one **dorsal,** which is **sensory** in function. Both of these unite lateral to the spinal cord. Immediately distal to this union there is a branch extending to the sympathetic nerve cord. This branch is known as the **ramus communicans,** and extends ventrad.

Before the union of dorsal and ventral nerve roots takes place a **spinal ganglion** or **dorsal ganglion** is seen lying in the dorsal roots. This ganglion is formed from the neural crests, and grows toward the cord, thus forming the dorsal root, but there are also fibers growing away from the cord from this same ganglionic region which are known as **peripheral nerves.**

The ventral roots (Fig. 290) are formed by fibers growing out from the lateral portions of the cord itself, and are thus **efferent** nerves carrying motor impulses from the brain and spinal cord to the muscles.

The **sympathetic ganglia** (Figs. 268, 290, 298) arise from cells which have migrated ventrally from the neural crests to form cell masses on each side of the midline on a level with the dorsal aorta. They are connected to form cords, and on the fourth day enlargements can be seen on these cords opposite the dorsal ganglia. These enlargements are the **primary sympathetic ganglia,** each one of which is connected by a **ramus communicans** to the corresponding spinal nerve. Later, both sensory and motor fibers will extend to the sympathetic ganglia from the spinal nerve roots as **rami communicantes,** while fibers running out from the sympathetic ganglia connect with the various organs of the body.

THE ORGANS OF SPECIAL SENSE

THE EYE (Fig. 289)

We have already discussed the projections from the fore-brain which are to form the optic cups as well as how the ectoderm directly opposite the optic cup thickens to form the lens, this lens then meeting with the cup.

On the fourth day the beginning of almost all the adult structures of the eye can be seen.

The thickened internal layer of the optic cup will give rise to the sensory layer of the retina.

The fibers which arise from the nerve cells in the retina grow along the groove in the ventral surface of the optic stalk toward the brain to form the optic nerve.

The external layer of the optic cup will become the pigment layer of the retina.

About the inside of the optic cup a grouping of mesenchymal cells can be seen which gives rise to the sclera and the choroid coat.

Some of the mesenchymal cells even make their way into the optic cup through the choroid fissure, and give rise to the cellular elements of the vitreous body.

From the margins of the optic cup closest to the lens, the ciliary apparatus of the eye is derived.

From the superficial ectoderm which overlies the eye, the corneal and conjunctival epithelium are derived.

The mesenchymal cells which migrate to the region between the lens and the corneal epithelium give rise to the **substantia propria** of the cornea. The lens forms as a thickening of the superficial ectoderm, which then becomes depressed so that it forms an invagination into the optic cup. The margins of the cup narrow and converge toward the lens, while the lens itself loses its connection with the superficial ectoderm and forms a completely closed vesicle. A microscopic study of sections of the lens show an elongation of the cells on that side of the lens which lies toward the center of the optic cup. These elongating cells are to become the **lens fibers.**

THE EAR

The auditory placode has already been mentioned as forming on the second day. This thickening of the ectoderm sinks below the surrounding ectoderm and becomes the floor of the auditory pit. This separates from the superficial layer from which it formed. It will be remembered that this causes the auditory pit to lie close to the myelencephalon. The tubular connection formed by the constriction of the region between the sunken placode and the superficial layer where it originally forms, remains open for a time as the **endolymphatic duct.**

It is by a series of complicated changes that this placode, which forms a vesicle, gives rise to the entire epithelial portion of the **internal ear** mechanism.

Nerve fibers from the **acoustic ganglion** grow **inward to the brain** and **outward to the internal ear,** thus forming its nerve connections. The external auditory meatus cannot yet be seen, nor has the dorsal and inner part of the hyomandibular cleft as yet given rise to the Eustachian tube, which is to form later.

THE NOSE (Fig. 304)

The olfactory pits are merely paired depressions in the ectoderm of the head, ventral to the vesicles of the fore-brain and just anterior to the mouth. These pits become deepened by the growth of the surrounding parts. The epithelium of the pits ultimately comes to lie at the extreme upper part of the nasal chambers, and there constitutes the **sensory epithelium.** Nerve fibers grow inward from these cells to the lobes of the fore-brain, constituting the **olfactory** or **first cranial nerves.**

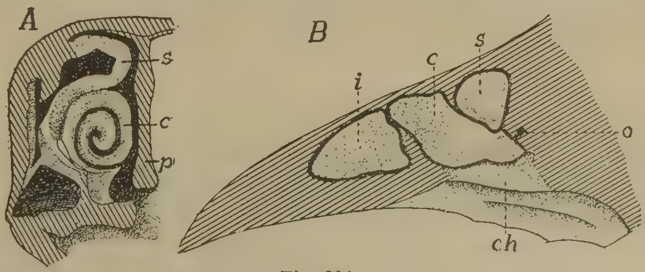


Fig. 304.

Olfactory region of the hen, *A* in transverse and *B* in longitudinal section. *c*, middle concha; *ch*, choana; *i*, inferior (anterior) concha; *o*, connection of air cavity with head; *p*, septum of nose; *s*, superior concha. (From Kingsley after Gegenbaur.)

THE SKELETAL STRUCTURE

On the fourth day the mesoderm surrounding the brain has increased and begins to show slight traces of the skull formation toward the anterior portion of the head, and extending posteriorly. The **fronto-nasal process** has already been discussed as well as the formation of the upper and lower jaws.

The beginnings of the vertebral column are also in evidence, though only to a slight extent. Nevertheless, it is well at this point to summarize what will occur, so that future changes will be understandable.

During the fourth day the somites have increased from about thirty to forty, each somite showing a more or less distinctive division into an outward lying **muscle plate,** and an inner region which is to form the vertebral column. It is from these inner portions that processes of mesoderm are sent out by both dorsal and ventral regions to the neural canal, as well as below the notochord, until these structures are completely surrounded by mesoderm. By the end of the fourth day these processes have become thickened, and are often called the **membranous vertebral column.** The membranous vertebral column is still segmented, each segment corresponding to the original somite from which it sprang.

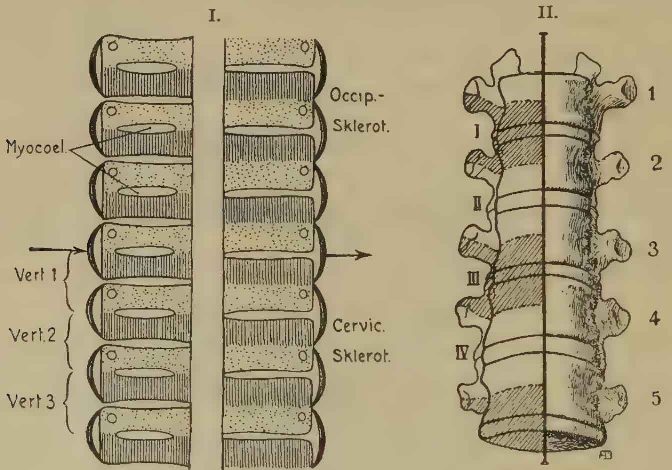


Fig. 305.

I, Redividing of the spinal segments. On the left side of the cut the sclerotomes and myotomes are seen in their original state. On the right they are seen in their final state. The cephalic portions are dotted and the caudal portions hatched. The arrows show the line of demarcation between head and neck. II, Ventral view of spinal column to show redivided parts of each vertebra. (From Corning, after Kollmann.)

On the fifth day these lines of segmentation disappear in the mesoderm which becomes continuous in its surrounding of the neural canal and notochord, though the muscle plates retain their segmentation.

On the fifth day also, the mesoderm lying in immediate contact with the notochord becomes cartilaginous, to form a cartilaginous sheath around the notochord throughout its entire length, while at each side of the spinal cord paired bars of cartilage form, which will shortly fuse with the cartilaginous sheath of the notochord to form the beginnings of the neural arches.

Toward the end of the fifth day the points opposite the attachment of the neural arches become thickened and more mature, but the portions between the neural arches retain their embryonic character. This causes what has been called a **secondary segmentation** of the cartilaginous tube. Later this segmentation becomes still greater until the entire cartilaginous tube is made up of a series of vertebral rings or segments, each segment consisting of a vertebral ring with its attached neural arch, and the anterior-posterior halves, respectively, of the succeeding and preceding intervertebral rings. Each of these segments becomes one of the vertebrae which constitute the spinal column.

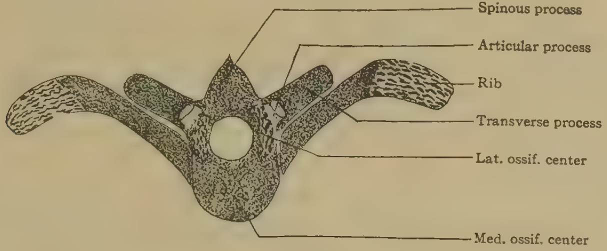


Fig. 306.

Thoracic vertebra and ribs of human embryo of 55 mm. (Middle of 3rd month) to show ossification centers. Cartilage is indicated by stippled areas, and ossification centers by irregular black lines. (After Kollmann.)

It must be understood, however, that these so-called secondary segments do not correspond with the somites from which they were formed. The secondary lines of segmentation lie at about the center of the muscle plates (Fig. 305), so that each of these secondary segments obtains approximately one-half of the muscle action from the immediately anterior muscle plate, and one-half from the immediately posterior muscle plate, thus making it possible for each one of the vertebrae to have the muscles from two regions act upon it.

The spinal column develops around the notochord.

Ossification of the vertebrae begins about the twelfth day in the **centrum** of the second or third cervical vertebra, gradually extending caudad. The neural arches ossify still later, there being two **centers of ossification** for these. (Fig. 306.)

On about the seventh day, the centrum of the first cervical vertebra, or atlas, separates from the rest of the bony ring and becomes attached to the axis to form the **odontoid process.**

On the seventh day there are present about forty-five vertebrae.

The most posterior five or six fuse a little later and form the **pygostyle** (Fig. 418).

THE EXCRETORY SYSTEM

The anterior tubules of the Wolffian body disappear before the end of the fourth day, while the posterior tubules have increased in size and become convoluted. The intermediate cell mass from which they arise is quite prominent. In cross-sections the convoluted tubules will naturally be cut at all angles, but they can be distinguished from the duct by observing their much thicker walls. The glomeruli can also be seen filled with blood vessels.

The permanent kidney, or metanephros (Fig. 307), begins its development toward the fourth day in the region lying between the Wolffian body and the cloaca, that is, between the thirtieth and thirty-fourth segment.

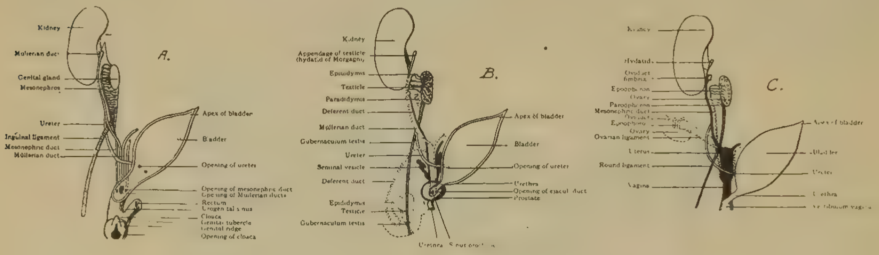


Fig. 307.

Diagram of Urogenital Organs. *A*, in Indifferent stage. *B*, development of the male from the indifferent anlagen, and *C*, development in the female from the indifferent anlagen.

The dotted lines represent the organs in their relative positions in the adult stage with the exception of the Müllerian duct in the male and the mesonephric duct in the female. These latter ducts disappear for the most part. (After Hertwig.)

The metanephric duct or **ureter** forms first, as did the ducts of the pronephros and the mesonephros. This duct grows forward on the outer side of the mesoderm lying in the region just mentioned. It grows from the dorsal side of the posterior end of the Wolffian duct anteriorly. Naturally it has an opening into the Wolffian duct from which it is a diverticulum, but on the sixth day it develops a separate opening into the cloaca.

It is from these ureters that lateral outgrowths arise which join with the rods of tissue now forming in the surrounding mesoderm. These outgrowths then develop into the tubules and Malpighian bodies of the metanephros in a similar manner to the way the Wolffian bodies developed.

The permanent kidney is quite small when compared with the metanephros but increases in size to a considerable extent just before hatching.

THE REPRODUCTIVE SYSTEM (Fig. 307)

On the fourth day a thickened strip of peritoneum forms on the lateral and superior face of the Wolffian body, which later extends all the way to the cloaca. This may be called the **tubal ridge.** It appears first at the anterior end of the Wolffian body and grows posteriorly, immediately external to the Wolffian duct. This tubal ridge invaginates, forming a groove-like arrangement at the cephalic end of the Wolffian body, and the lips of this groove then fuse and form a tube—the **Müllerian duct.** Fusion takes place on the fifth day. The anterior end of this Müllerian duct remains open and is to become the opening into the coelom of the oviduct which the Müllerian duct later becomes. There are several openings which will develop at the anterior end in addition to the main one, but these latter close normally. Should they remain open, the abnormal condition of having two openings in the duct results in the adult stage. The posterior end remains closed.

The older embryologists considered these two or three openings in the Müllerian duct as homologous with the nephrostomes of the pronephros, and so insisted that the pronephros followed the mesonephros in the chick. Modern embryologists consider that these openings lie entirely too far posteriorly and laterally to permit of this older interpretation.

In both sexes so far, development has been alike, but on the eighth day the Müllerian ducts begin to degenerate. They disappear almost entirely by the eleventh day in the male.

In the female chick, the left Müllerian duct forms the oviduct, while the right Müllerian duct degenerates. The left one alone remains functional.

The Wolffian body disappears almost entirely in the male, though a small group of tubules covering the anterior head of the testes remains as the **epididymis.** In the female it also disappears almost entirely, the part remaining being the **parovarium,** a small body lying in the mesentery between the ovary and the kidney.

The Wolffian duct disappears entirely in the female, but it acts as the **vas deferens** or sperm duct in the male.

The germ cells probably arise from the entoderm in vertebrates. The entoderm is never metameric, though some of the older embryologists spoke of metameric **gonotomes** as primitive segmented regions which were to form the gonads.

At about the time the somites form, the portion of the entoderm which is to become the gonads, migrates through the developing mesoderm in the epithelium of the genital ridges which have formed immediately lateral to the mesentery. The primitive or **primordial ova** or sperm can be recognized not only from their size but from their reactions to microscopic stains (Fig. 254).

In the female, the epithelium increases in thickness to an enormous extent. The primitive ova multiply, and the products of this multiplication, accompanied by some of the epithelial cells, sink into the deeper stroma of the connective tissue, and thus form **ovarial** or **medullary cords,** each such cord containing a number of ova. The cords then break up, each egg becoming surrounded by a layer of epithelial cells, the whole forming a **Graafian follicle.** The follicle cells supply the nourishment to the egg lying within.

This whole growth takes place only on the left side of the chick, as the right ovary is not functional.

In the male, the beginnings of the gonad formation are similar to that of the female, but instead of the cords breaking up into separate follicles, each cord develops a lumen which becomes converted into the **seminiferous tubule.** One can, however, see in the walls of these tubules both types of cells that were seen in the Graafian follicle. Indeed, there is found a third type of cell called **Sertoli's cell,** which is supposed to act as a sort of nutritive or **nurse cell** to the developing sperm.

THE ADRENAL BODIES

While these bodies lie closely attached to the kidney, they have not developed as a part of the urinary system.

It is important to know that the adrenal organs, which are among the prominent ductless glands now studied in the schools, arise from two separate and distinct origins:

First, by a proliferation of peritoneum, and second, by a proliferation of the sympathetic ganglion cells. It is the portion arising from the peritoneum which connects with the mesonephros.

The peritoneal proliferations begin as cords or strands of cells along the dorsal aorta. These then connect with the renal vesicles of the mesonephros. Later, the sympathetic proliferations extend within the peritoneal cords, so that the peritoneal cords now become the **cortex** and the sympathetic portions become the **medulla** of the adult adrenal glands.

THE CIRCULATORY SYSTEM

At this point it is well for the student not only to realize, but to appreciate the great number of experiments necessary to demonstrate biological facts, as well as to understand the great number of possible errors and objections which men may bring forth to oppose the interpretation of these facts after the facts themselves have been demonstrated.

Suppose the question be raised as to whether the first beating of the heart of an embryo is muscular or nervous in type. What experiments, for example, would be necessary to answer such a question satisfactorily?

Off hand, one might say, that as nerves carry impulses to all muscles, and as there are nerves in the heart muscle, the action must be nervous.

Nerve fibers grow into the heart muscle from the nerve cells close by, but the very finest nerve stains known, have been unable to demonstrate that there are any nerves whatever in the heart muscle at the time of its earliest beating. It may be objected that however fine our nerve stains may be, they are not sufficiently so to demonstrate possible nerve cells or parts of nerve cells. And, that if we improve in our technical ability by obtaining new stains, we may expect to find nerve-cell-substance heretofore unseeable. This objection is not well taken, because if any muscle be removed from the body and placed in normal salt solution, the muscle fibers do not lose their contracting ability, although in a few days the nerves degenerate and can be dissected out. If, then, our present stains do show the nerve fibers clearly in embryos, and these can be seen to be in exactly the same position as in the adult heart, as demonstrated by the experiment just cited, it is quite reasonable to assume that the stains do show all the nerve fibers that are actually present. If this be true, we can demonstrate that all such nerve fibers, which normally take a stain, have been destroyed. **But, the new nerveless muscle still contracts and expands.**

It could, of course, be argued that in so far as this is embryonic material not yet far removed from the germ plasm, that, therefore, every particle of the embryonic material still retains some of the undifferentiated nerve cells, and consequently every part of the embryo does actually retain some slight nervous substance which may, under extraordinary circumstances, be brought forth.

This objection is overcome by an experiment performed some years ago by taking a portion of the adult intestinal tract, chopping it up very finely, and placing it in a test tube. Notwithstanding the fact that it was thoroughly chopped up, this substance still was able to digest food placed in the tube with it. Those who insist upon all action being nervous in type, then contended that the different particles of the intestine still retained some of the essential parts of the nerve cell, so that, notwithstanding the parts being cut up into very tiny particles, the essential nervous elements were still doing the work.

A portion of intestine was then kept in a chemical medium similar to that mentioned in the heart-experiment, and, as with the muscle-experiment, the nerves degenerated and were dissected out, but the intestine itself continued performing its normal functions.

If the tough adult nerve-structures are so easily degenerated in a normal salt solution, it is surely safe to assume that the hundredfold more delicate embryonic nerve structures will also be destroyed in such a medium.

It will be remembered that the heart grows as a simple straight tube, and that the blood is formed in the blood-islands by the cavities flowing together. As these cavities fuse they became tubular, forming the vitelline veins which carry the blood to the heart.

It is of the utmost importance to remember that this early heart tube, even before the blood passes through it, has a slow, irregular "beat." This, however, is not a true heart-beat, but merely the functional movement of living muscle.

The true heart-beat is established at that particular moment when the thin membrane which separates the anterior from the posterior portion in the tubular heart breaks through by the greater pressure of the blood from the posterior region pressing forward. The tiny membrane can be seen to bulge out toward the head region until it finally breaks.

From that moment on, the blood forces its way through the heart and begins a rhythmic muscular reaction on the part of the heart.

The architecture of all muscles is such that various muscle cells are antagonistic to other muscle cells in the same group, so that each muscle can, if it elongates, also contract and shorten, the two sets of fibers being mutually antagonistic, so as to retain a normal balance. The heart muscle shows this principle admirably in that it is composed of two groups of spirally wound muscle fibers, the one unwinding as the other winds up, thus causing a mutual interaction which keeps up by the rhythm of the heart-beat.

From the study of physics we know that when two streams which run in different directions meet, a **vortex** is formed. If we now turn to our earlier description of the development of the circulatory system during the first two days, we shall find that there are two openings into the heart from which streams of blood are brought into that organ. As these two blood vessels send their streams together, a vortex is formed. We thus find a physical explanation as to why the heart muscles follow in their growth the optimum stretching caused by the spirally running stream of blood.

From all that has been said above, it follows that when a heart is removed from an animal body and kept "alive" for days or weeks, it is but the physical continuation of the normal muscular antagonistic reaction of the two spiral shaped groups which have been wound up quite as a clock is wound.

As months and years have elapsed in the winding of these spiral muscles, it is quite natural to understand that they are still sufficiently wound when removed from the body so that they will continue in action for some days if no external conditions exist to cause a stoppage sooner. Such external conditions may be pressure, friction of various kinds, or a drying up of the tissues when not retained in proper media.

If the immediately preceding paragraph be remembered, one can always explain such objections as this: "If potassium is removed from the medium in which a heart is placed, it ceases to function, thereby proving that it is the potassium solution which causes the reaction." It will be remembered that it was stated in the preceding paragraphs that the action of the muscles will continue for some time until external conditions cause a stoppage. The removal of potassium solution from the surrounding medium has nothing to do with the reaction ability in the muscle cell itself, but its removal removes a factor necessary to reaction, by making the **medium** one in which it cannot react. An example may make the matter clearer. A living human being has the power to move his arms and walk about. This power is retained for many years. Let us suppose that we remove certain substances from the air which are needed for his lungs to function. An individual breathing such an atmosphere would either slowly or rapidly (depending upon what gases are removed) grow less and less able to move his arms or to walk, and in a short time this ability would cease entirely. In other words, such an individual needs a certain kind of atmosphere for breathing purposes, without which he cannot perform his normal functions. This, however, is vastly different from saying that the constituents of air are the cause of his being able to move.

From what has been said above, all that we can say, in regard to nerve-and-muscle-action, is that experiments tend to demonstrate that muscle cells **have the ability to act and react,** and that the **nerves are only the connectors and impulse carriers,** by which a coördination of muscle cells, which are not in contact with each other, may be brought about.

In the embryo the yolk is converted into blood, and the pressure of that blood as it passes through the various vessels with its greater posterior and its less anterior pressure, brings about the results mentioned above. In the adult, the food that is taken in and converted into blood, works on quite similar principles by continuing to produce a greater posterior than an anterior pressure.

The embryonic circulation can only be understood when it is realized that it varies from the adult circulation in a manner that is accounted for by the difference between embryonic and adult feeding. In the embryo, due to the food coming entirely from the yolk, there is developed a **yolk** or **vitelline-circulation.** As the chick's lungs are non-functional before birth, and the allantois functions as a respiratory organ, there is developed an **allantoic circulation,** while a third type is the circulation of the embryo itself. The vitelline and the allantoic together constitute the **extra-embryonic circulation.**

All food material to the embryo comes from the yolk (although the yolk particles do not turn directly into blood. It is the action of the entodermal cells which line the yolk-sac and pour out a secretion of enzymes, which breaks down the yolk granules). It is thus seen that it is the vitelline vessels which carry food into the embryo, and it is the allantois which serves both as a respiratory and excretory organ (at least until the nephroi are formed). It is the allantoic circulation which permits the escape of carbon dioxide and other waste matters.

Therefore, the intra-embryonic circulation has nothing to do with either manufacturing blood or throwing out waste matter (until the nephroi are formed); it serves only as the **carrier, distributor,** and **collecting system** of both food and waste materials.

As all three systems, **intra-embryonic, vitelline,** and **allantoic** send their vessels to and from the heart, the contents of all three systems mingle in that organ, although of course the vitelline circulation is the richer in food material, and the allantoic the richer in waste matter.

It is at this point that the student must again remember that arteries need not necessarily carry blood rich in food matter, but that an artery is any blood-vessel carrying blood **away** from the heart under a high pressure. This pressure probably accounts for the fact that arterial walls are thicker and stronger than venous walls.

Veins are the carriers of blood to the heart.

THE VITELLINE CIRCULATION

This has been described in detail at an earlier period.

THE ALLANTOIC CIRCULATION

We have already spoken of paired vessels extending through each segment of the embryo which arise from the aorta at about the level of the allantoic stalk. One pair of these segmental vessels increases in size as the allantois grows, and is distributed over the allantois in a rich plexus. As the allantois lies close under the shell, there is thus afforded a large area where gases can easily be exchanged and oxygenation be brought about. After such oxygenation and the extrusion of the carbon dioxide, the allantoic blood is gathered by the allantoic veins, and carried back to the heart.

The excretory ducts later develop in the embryo and then empty into the allantoic stalk close to its cloacal end. It is at this time that the allantois begins to function as a receptacle for solid waste matters, which, after the fluid parts have been evaporated, retains this waste-matter until it is thrown off at the birth of the animal.

The right and left allantoic veins run cephalad in the lateral body-walls of the chick, and enter the sinus venosus, one on each side of the omphalomesenteric vein. These two allantoic veins will shortly fuse and form a single **umbilical vein** (Fig. 308).

The yolk-sac is regarded as a diverticulum of the intestine, and the allantois as a diverticulum of the urinary bladder, which itself is an outgrowth of the alimentary tract.

These outgrowths carry their blood vessels with them. Therefore, the omphalomesenteric artery and the vitelline veins (these latter are

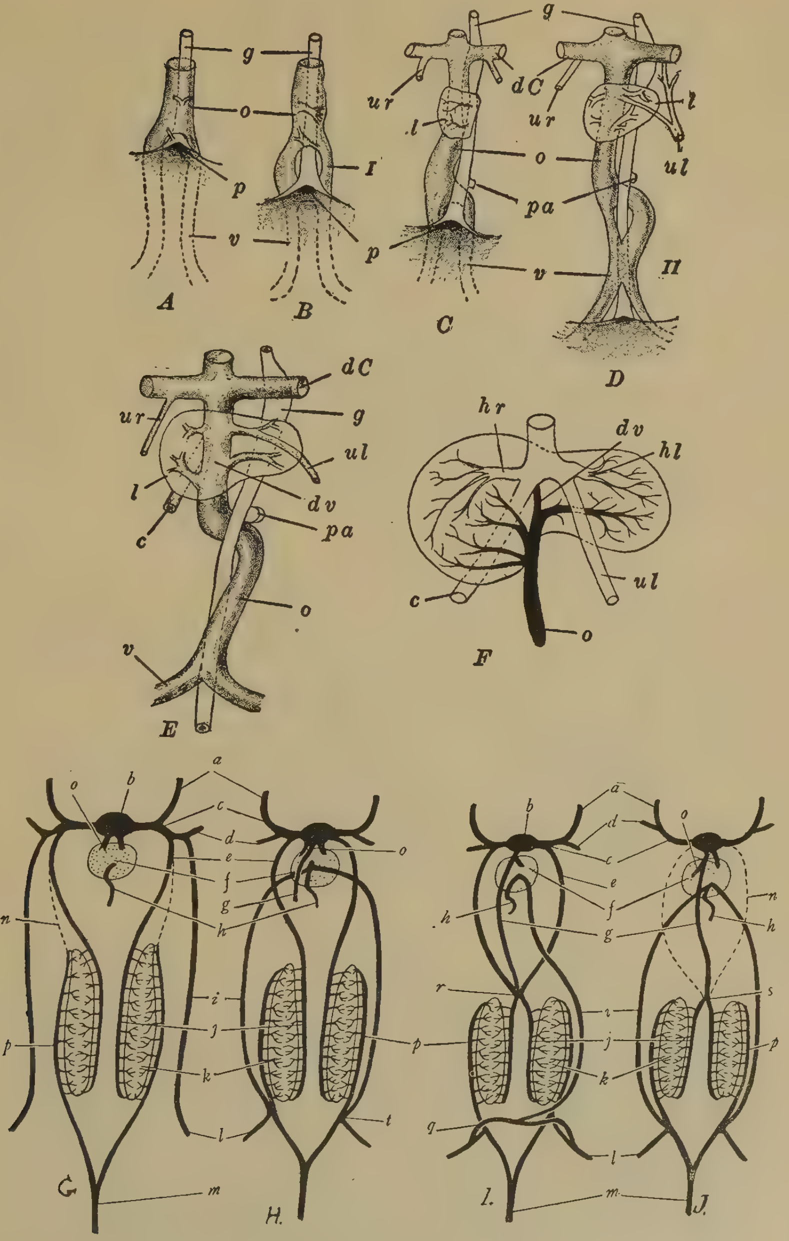


Fig. 308.

A to *F*, Diagrams illustrating the formation of the omphalomesenteric and umbilical veins, in the chick. *A*. At about fifty-eight hours. *B*. At about sixty-five hours. Veins joined dorsal to the gut. *C*. At about seventy-five hours. Veins again separate. *D*. At about eighty hours. Secondary union of veins around the gut. *E*. At about one hundred hours. Definite arrangement of the vessels. *F*. Relationship of liver vessels. *c*. Vena cava posterior (inferior); *dC*, ductus diverticula of the omphalomesenteric veins) extend out over the yolk, constantly increasing as to both absolute numbers and as to branches, as the yolk-sac spreads over the yolk.

The allantoic arteries are also called umbilical arteries. They are what will later be known as **hypogastric arteries.** In birds and reptiles five vessels, three arteries (one omphalomesenteric and two allantoic), and two veins (one vitelline, really omphalomesenteric, and one allantoic), connect the embryo freely through the umbilical stalk (Figs. 284, 297, 308).

In mammals, where there is little or no yolk, the yolk-sac is reduced or absent entirely and the omphalomesenteric and vitelline vessels disappear very early, so that the umbilical cord or stalk contains only the two allantoic arteries and one allantoic vein.

In the dogfish and all elasmobranchs, where there is a large yolk-sac but no allantois, the vitelline circulation alone is found, the allantoic not being present.

THE INTRA-EMBRYONIC CIRCULATION

The large vessels communicating with the heart are the first ones to appear in the chick embryo. At thirty-three hours the ventral aorta extends headward, bifurcating ventral to the pharynx to form a single pair of aortic arches. This pair of arches passes dorsad around the pharynx, then running tailward on the dorsal wall of the gut as the paired dorsal aortae (Fig. 277).

On the second day, as the visceral arches and clefts appear, this original pair of aortic arches comes to lie in the mandibular arch. In each of the visceral arches posterior to the mandibular, new aortic arches are formed, which connect the ventral aortae with the dorsal aortae.

At fifty-five hours we saw there were three pairs of these aortic

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Cuvieri; *dv*, ductus venosus; *g*, gut; *hl*, left hepatic vein; *hr*, right hepatic vein; *l*, liver; *o*, omphalo-mesenteric vein; *p*, anterior intestinal portal; *pa*, rudiment of pancreas; *ul*, left umbilical vein; *ur*, right umbilical vein; *v*, vitelline vein; *I*, *II*, primary and secondary venous rings around the gut. (After Hochstetter.) *G* to *J*, Diagrams to show the origin of the postcaval vein and the changes in the abdominal vein in amphibians and reptiles. *G*, elasmobranch stage. The lateral abdominal veins *i* enter the common cardinal veins *c* and are not connected with the renal portal veins *p*. *H*, the lateral abdominals *i* have joined the renal portals at *t* posteriorly, and anteriorly pass into the liver *f*, where they unite with the hepatic portal vein *h;* a new vein, the postcaval vein *g*, is seen growing caudad from the liver *f*, where it arises from the hepatic veins *o*. *I*, condition in the adults of urodele amphibians; the postcaval vein *g*, has reached and fused with the posterior cardinals *e* and and the subcardinals *j* at the point *r;* the two lateral abdominal veins have united to form the ventral abdominal vein *i* which empties into the hepatic portal *h*. *J*, condition in adult reptiles; the anterior portions of the posterior cardinal veins *n* are obliterated, leaving the postcaval vein *g* as the sole drainage for the subcardinals *j* and the kidneys *k;* the two lateral abdominal veins remain separate as in elasmobranchs. *a*, anterior cardinal vein; *b*, sinus venosus; *c*, common cardinal vein; *d*, subclavian vein; *e*, posterior cardinal vein; *f*, liver; *g*, postcaval vein; *h*, hepatic portal vein; *i*, lateral (or in *I*, ventral) abdominal vein; *j*, subcardinal vein; *k*, kidney; *l*, iliac or femoral vein; *m*, caudal vein; *n*, obliterated part of the posterior cardinals; *o*, hepatic veins; *p*, renal portal veins; *q*, pelvic veins; *r*, union of postcaval, posterior cardinals, the subcardinals; *s*, union of postcaval and subcardinals; *t*, union of abdominal vein with the renal portal system. (From Hyman's "A Laboratory Manual for Comparative Vertebrate Anatomy," by permission of The Chicago University Press.)

arches with a fourth pair just beginning to form. It is at about this period also that there is an extension headward from the dorsal aortic roots. These extensions form the **internal carotid arteries** which supply the brain.

The **external carotid arteries** arise later from the ventral aortic roots. They also grow cephalad as do the internal carotid arteries, but, unlike the internal carotids, the external carotids **supply the face.**

By the end of the fourth day two more pairs of aortic arches appear posterior to those already present. The fifth pair of aortic arches is very small and disappears in a short time.

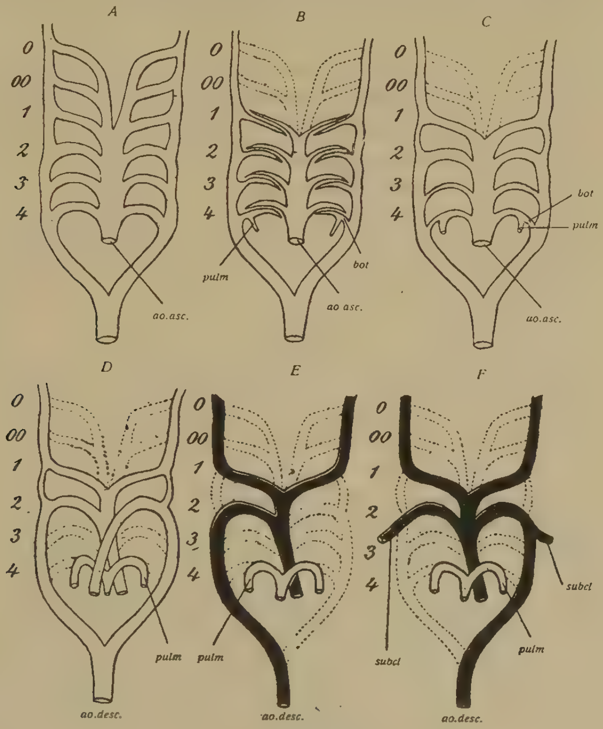


Fig. 309.

Schematic diagrams illustrating the changes which take place in the aortic arches. *A*, embryonic prototype; *B*, Fishes; *C*, Urodeles; *D*, Lizard; *E*, Birds; *F*. Mammals.

The dotted lines show the portions which have become obliterated in the adult forms of the animals mentioned. *ao.asc.*, ascending aorta which branches into the following aortic arches: 0,00, 1, 2, 3, 4,; *ao.desc.*, descending aorta; *bot*, duct of Botallus; *pulm*, pulmonary artery; *subcl*, subclavian artery; 0,00, 1, 2, 3, and 4, the six aortic arches. (After Boas.)

The first and second arches have become smaller and also finally disappear. Probably most often the entire first arch has disappeared by this time and sometimes the second has also gone.

Consequently, there are present only the **third, fourth,** and **sixth** pairs. While these arches do not remain intact permanently, though parts of them do, it is from these three pairs that the main blood vessels arise.

In reptiles, birds and mammals, all the main vessels of the adult connecting the heart with the dorsal aorta are derived from the **fourth pair** of embryonic aortic arches.

It is important to remember this, as our studies in comparative anatomy will consist of the study of an **amphibian, a dogfish, a turtle, and a cat** or **rabbit,** and the student will be required to show similarities and differences of this nature in the different groups.

In reptiles the aortic arches remain in pairs (Fig. 309), but in birds **the left arch degenerates,** while in **mammals it is the right arch which degenerates.** The dorsal aortae, which began as paired vessels, now fuse close to the sinus venosus. The portion extending cephalad is fused for a very short distance, though never involving the region of the aortic arches.

Quite early in development there are segmental vessels arising from the aorta which extend into the dorsal body-wall. The pair at a level with the anterior appendage-buds enlarge and extend into the wing-buds as the **subclavian arteries.**

We have already mentioned the pair opposite the allantoic stalk which has enlarged to become the **allantoic arteries.**

The **external iliac arteries** which supply the posterior appendage-buds arise as branches from the allantoic arteries close to the origin of the aorta.

At four days, the chick embryo still has the omphalomesenteric arteries as its main visceral supply. It will be remembered that these arteries are paired originally, but as the embryo (which must be considered as having its ventral portion open and thus lying extended over the yolk of the egg), comes to have its ventral walls meet and grow together, the omphalomesenteric arteries, like the heart and other paired structures which later become fused to form a single vessel or organ, are brought together and fused, thus forming a single vessel which comes to lie in the mesentery and runs from the aorta to the yolk-stalk.

The proximal portion of the omphalomesenteric artery persists as the **superior mesenteric** of the adult, after the atrophy of the yolk-sac.

The **inferior mesenteric artery** and the **coeliac artery** arise from the aorta independently at a later stage.

The **cardinal veins** are the main **afferent systems** of the early embryo. They form on the second day as paired vessels on each side of the midline and extend both headward and tailward. The anterior and posterior cardinal veins on the same side come together to form the **duct of Cuvier,** which duct runs ventrally and enters the **sinus venosus.** On the fourth day there is practically no change in the cardinal veins.

Later, the proximal portions of the anterior cardinal veins become connected by a new **transverse vessel** which forms, and enters into the venous atrium of the heart, while the distal portions remain as the **jugular veins** of the head region.

The **posterior cardinal** veins (Figs. 301, 308), lie in the angle between the somites and the lateral mesoderm. It is of importance to locate these vessels and understand their position, as the excretory system develops in close relationship to them later, and their relation to the excretory system cannot be understood unless their developmental process is closely followed at this stage.

The mesonephroi develop **from the intermediate mesoderm** so that the posterior cardinal veins lie just dorsal to them throughout their length (Fig. 301).

In fact, the posterior cardinal veins are the principal afferent vessels of young embryos. However, in the adult these posterior cardinal veins are going to be replaced by the large **vena cava.**

With the foregoing in mind as a sort of general bird's-eye view of what has taken place and what will take place in the main blood vessels, we shall enter into a little more detail.

THE HEART

The heart began as a paired structure. When the ventral walls of the embryo came together, the two portions of the heart also came together, and formed a single tube in the midline of the body, close to the ventral portion.

After this fusion, the heart is nearly straight and double-walled. The endothelial lining of the heart has the same structure and is continuous with the entering and outgoing blood-vessels.

There is a thickened layer over the heart called the **epimyocardium,** which later separates into a thickened muscular layer, the **myocardium,** and a thin non-muscular covering called the **epicardium.**

As the paired tubes have come together to form the single heart, the splanchnic mesoderm from each side of the body has also come together to form the dorsal and ventral **mesocardia** (Fig. 275).

The ventral mesocardium disappears almost immediately after its formation, but the dorsal mesocardium continues suspending the heart for some little time, also disappearing ultimately, except at the more caudal portion of the heart.

As already described, the heart, now lying in the **pericardial cavity,** is attached at both ends and grows much more rapidly than the surrounding body, so that it begins to fold upon itself. The bending of the organ must be carefully studied or later work upon the heart will have little meaning. (Figs. 274, 276, 279, 280, 283, 287.)

It will be noted that the cephalic end of the heart is attached just where the aortae leave it, while the caudal end of the heart is attached where the omphalomesenteric veins and the dorsal mesocardium meet.

It will also be noticed that the caudal or **ventricular** end grows toward the right.

The physical restriction placed upon the growing heart by the dorsal bending of the entire embryo, and the pushing in of the yolk dorsally, plus the fact that the entire embryo (by torsion) comes to lie upon its left side, accounts for the particular shape and direction of the heart's bending.

As the U-shaped bend continues to grow, the closed portion of the U is forced caudad, and twisted upon itself to form a loop. This forces the **atrial** (arterial region) portion slightly to the left (that is, toward the yolk) and the conus arteriosus is thrown across the atrial region by being bent to the right (or away from the yolk), and then caudad. The closed portion of the loop is the **ventricular region.** By this twisting process the original cephalo-caudal relations of the atrial and ventricular regions have become reversed, the atrial region now lying cephalad to the ventricle.

Not only has the position of the two regions become reversed, but there is a constriction forming which divides atrium from ventricle (Fig. 283). The constriction itself is called the **atrio-ventricular canal.**

It is on the fourth day that the bulbus arteriosus becomes attached to the ventral surface of the atrium. The bulbus pressing inward, the atrium grows as a seeming expansion around each side of the bulbus, and it is these lateral growings which indicate right and left divisions of the atrium, which later separate entirely.

The ventricle has an indication of a right and left division also at this same time, caused by a longitudinal groove appearing on its surface.

The bulbus later divides to form the **root of the aorta** and the **pulmonary artery.**

Though the heart began its formation at the level of the hind-brain, it has come to lie now at a level with the anterior appendage-buds, and as the ventricular portion which is the more unattached, it is this ventricular region which extends the more caudad.

Histologically, the endocardium of a four-day chick is still a single layer of cells, while the myocardium can be distinguished from the outer epicardium. The myocardium is composed of elongated cells which show some resemblance to the muscle cells which they are to form. They are arranged in bundles extending toward the lumen. These bundles will become the **trabeculae carnae** of the adult heart.

The cells of the epimyocardium are becoming flattened to form the true epicardium, while loosely placed mesenchymal cells lie in the region between endocardium and myocardium near the atrio-ventricular canal. These mesenchymal cells will take part at a later period in forming the various septa which are to divide the heart into chambers as well as the connective tissue frame-work of the valves.

The ventricular septum is completed at about the sixth day, its anterior edge fusing with the posterior edge of the septum which divides the truncus arteriosus into right and left halves.

The anterior edge of the septum of the truncus arises between the fourth and fifth aortic arches in a manner which causes the blood coming from the left side of the truncus (that is, from the left ventricle) to pass through the third and fourth aortic arches, while the blood from the right ventricle passes into the fifth aortic arch.

About the seventh day the right and left parts of the truncus separate completely from each other. The right branch remains connected with the fifth aortic arch as the pulmonary trunk, and the left is connected with the third and fourth arches as the systemic trunk.

The ventral ends of the third arches become the subclavian arteries, carrying blood to the anterior appendages, while the dorsal communication between third and fourth arches disappears.

This means that the blood now passes from the left side of the heart through the third arch to the anterior appendages, and through the fourth arch to the dorsal aorta.

About the fifth day, the fourth pair of arches are the larger of any arches remaining, the left one, however, becoming smaller and smaller in size until it disappears almost entirely. The right fourth aortic arch grows larger and larger to form the **systemic arch** of the adult chick.

It has already been stated that in mammals it is the right arch which disappears, the left alone persisting as the systemic arch (Fig. 309).

Early on the third day the **pulmonary arteries** form in the walls of the lungs, and extend toward the fifth arch with which they connect at the ventral ends of these arches. The dorsal end of the fifth arch between the point of union of the pulmonary artery and the dorsal aorta is called the **duct of Botallus** (Fig. 309). This ductus Botalli offers the blood from the right side of the heart a passage into the dorsal aorta so that little passes through the capillaries. The duct, however, shrivels up at the time of hatching, and becomes entirely closed so that all the blood from the right side of the heart must pass into the pulmonary circulation. It is at this time that the lower portion of the aortic arch becomes the pulmonary artery.

THE VEINS

As has been stated several times, the anterior and posterior cardinal veins unite with each other on a side to form the duct of Cuvier and then enter into the **meatus venosus.** These anterior and posterior cardinals bring back the blood to the heart from practically all parts of the body except the digestive organs.

The anterior cardinals persist as the jugular veins to which the **pectoral veins** from the anterior appendages soon become joined. From the head and neck the **vertebral veins** also join the jugulars.

The posterior cardinals remain large as long as the Wolffian body is functional, but as the permanent kidneys develop, these veins become smaller and smaller and ultimately disappear.

The ducts of Cuvier persist in the adult chick as the **anterior venae cavae.**

The **posterior** or **inferior vena cava** develops from the meatus venosus, which was formed by the union of the two omphalomesenteric veins. To understand the evolving process by which the posterior vena cava comes into existence, it is necessary to follow carefully the development of the surrounding organs.

The liver forms as a diverticulum from the digestive tract. This diverticulum then grows around the meatus venosus until it completely surrounds the meatus. Blood-vessels form in the liver, extending toward the meatus venosus, into which they open by the fifth day.

At the posterior edge of the liver, there are a number of **afferent** hepatic vessels coming from the meatus venosus through which some of the blood coming to the heart from the vascular area may enter the capillaries formed in the liver substance.

At the anterior edge of the liver, where the meatus venosus might be said to be leaving the liver, there is a collection of **efferent hepatic** vessels whose distal ends are in direct connection with the capillaries of the afferent hepatic vessels.

The blood passing through the liver has two courses it may take. Most of it passes through the large meatus venosus into the heart, but some of it passes through the afferent hepatic vessels into the liver substance where it is collected by the efferent hepatic vessels and carried to the meatus venosus.

That part of the meatus venosus lying between the afferent and efferent hepatic vessels is often called the **ductus venosus.**

The two allantoic veins already described unite on entering the body to form a single vein emptying into the left (persistent) omphalomesenteric vein. It is well to remember that as the yolk-sac decreases in size, the allantois increases, and so, too, the relative size of omphalomesenteric veins and allantoic veins changes; the omphalomesenteric becomes smaller and the allantoic becomes larger, so that it almost seems as though the omphalomesenteric were a branch of the allantoic. Both of these veins disappear at the time of hatching.

The superior mesenteric artery was formed by the closure of the ventral body-wall so as to bring the paired omphalomesenteric veins together, to form a single vessel running from the aorta to the yolk-stalk. As the yolk-sac atrophies, the proximal portion of the omphalomesenteric artery becomes the superior mesenteric artery.

The **mesenteric vein** is formed by a union of the veins from the walls of the hinder part of the digestive tract, which there form a single vein. This vein is at first quite small, and empties into the omphalomesenteric vein just before the latter enters the liver. The point of entry may be said to be the beginning of where the omphalomesenteric vein becomes the meatus venosus.

It will, therefore, be noted that the blood which goes to the liver comes from three sources:

(1) Through the omphalomesenteric vein, from the yolk-sac. This blood is rich in food material and has been oxidized in the vascular area.

(2) Through the allantoic vein from the allantois. This blood is very rich in oxygen.

(3) Through the mesenteric vein from the digestive tract of the embryo. This blood is venous in character.

The **mesenteric vein** increases in size with the growth of the embryo, and after the omphalomesenteric and allantoic veins disappear at the time of hatching, it persists as the **hepatic portal vein** of the adult chick. This large vessel brings blood back from the hinder parts of the digestive canal to the liver.

On the fourth day the posterior or inferior vena cava proper arises. It forms between the posterior ends of the Wolffian bodies, and runs forward in the midline, ventral to the aorta. It joins the meatus venosus anteriorly between the heart and the anterior edge of the liver, and posteriorly it connects with the permanent kidney as soon as these are formed. It also connects posteriorly with the hind limbs and the caudal region.

The posterior vena cava is at first quite small, but as more and more blood is being sent from the developing metanephroi and the caudal region, it becomes even larger than the meatus venosus of which it was originally but a branch.

Just before the vena cava becomes larger than the meatus venosus, the efferent hepatic vessels have shifted their position so that they now enter directly into the vena cava instead of the meatus as formerly. In fact, before the time of hatching the entire portion of the meatus venosus lying between the heart and liver becomes obliterated, so that all blood flowing into the posterior end of the liver through the portal vein, passes into the posterior vena cava through the hepatic vein (Fig. 308, I, J).

The relative changes in the size of blood vessels must be clearly understood and followed, or the circulatory system of the embryo, and consequently, also the circulation of the adult will be hopelessly confused.

It is well at this point to obtain an idea of the embryonic circulation of a little later time than that of the fourth day which we have been discussing.

By the beginning of the sixth day, the septa which have already been mentioned have divided both auricles and ventricles into right and left halves (Fig. 283). However, neither of these septa are complete. The septum separating the two parts of the auricle develops perforations, and in the human heart these perforations form an oval-shaped opening called the **foramen ovale**, which may, in abnormal cases, remain open and thus cause a constant intermingling of venous and arterial blood. Usually, such persons do not live long, although there are notable exceptions. This inter-auricular foramen closes at the time of hatching, so that the blood from the right auricle can be sent to the lungs for aeration as soon as these organs become functional at birth.

The septa are sufficiently developed so that we may speak of four divisions or cavities in the heart. This makes a double circulation possible, namely, the systemic and the pulmonary (up to the time of hatching, the allantoic circulation takes the place of the pulmonary).

By this time, then, the heart is fully formed. The sinus venosus has been absorbed into the right auricle, of which it forms a part. The open foramina allow blood to pass back and forth between the auricles. The ventricular septum is more complete. The truncus arteriosus is divided into two separate vessels, the pulmonary trunk arising from the right ventricle, and the systemic trunk from the left ventricle.

The aortic arches which are still present are the third, fourth, and fifth, and small portions of the first and second.

The systemic trunk from the left ventricle leads to the third and fourth pairs of aortic arches, from which the head and fore-limbs are supplied.

The pulmonary trunk, arising from the right ventricle, leads to the fifth pair of aortic arches, which are directly continuous with the dorsal aorta. It is from these that the small pulmonary arteries arise.

It will be remembered that as the lungs are not yet functional, there is little use for these vessels until later. An omphalomesenteric artery carries blood to the yolk-sac and a large allantoic artery passes from the aorta to the allantois.

The venous system consists of the right and left anterior venae cavae, and the posterior vena cava. The former drain the head and fore-limbs, and the latter the posterior portions of the body, the limbs, and the kidneys.

Before reaching the heart, the posterior vena cava is joined by the ductus venosus, through which blood is returned from the yolk-sac, allantois, and embryonic alimentary canal, by the omphalomesenteric, allantoic, and mesenteric veins respectively.

All three venae cavae open into the right auricle of the heart, but due to the position and direction of the opening, and to a valve, the blood from the posterior vena cava is directed through the foramen ovale into the left auricle, while the blood from the right and left venae cavae (anterior) remains in the right auricle.

As the auricles now contract, the blood which has come from the posterior vena cava is forced into the left ventricle and passes out through the systemic trunk through the third and fourth pairs of aortic arches to the head and fore-limbs, while the blood from the anterior venae cavae passes out through the right ventricle through the pulmonary trunk and thus through the fifth aortic arches into the dorsal aorta, from where the blood goes to the body and hind-limbs of the embryo. A small portion, however, is carried out along the omphalomesenteric arteries to the yolk-sac and through the allantoic arteries to the allantois to take up nutriment and oxygen. In the early embryo, a much greater portion of this pulmonary circulation goes to yolk-sac and allantois.

It is assumed that the vastly greater proportion of blood supply to the anterior region, as contrasted with the smaller quantity to the posterior portions, accounts for the greater and more rapid development of the head region, which it will be remembered is the first part of the chick to develop.

The disproportionate development of the head may be realized when it is known that the human child at birth has a head about one-fourth the length of its entire body.

At about the time of hatching the ductus Botalli (which it will be remembered is that portion of the fifth aortic arch lying between the dorsal aorta and the point of origin of the vessel that runs to the lung) —(Fig. 309)—closes up entirely, so that the blood from the right ventricle must pass through the pulmonary veins back to the left auricle.

The lungs now become functional, and the true pulmonary circulation is established. The allantoic circulation, being no longer needed, ceases, while the allantoic arteries and veins disappear, as do also the omphalomesenteric arteries and veins when the yolk-sac has finished its work, and the hatched chick can take in its own food.

It is at this time also that the entire supply of blood which goes to the liver passes through the mesenteric vein, which is now called the **hepatic portal vein.** The ductus venosus has closed, and so all blood brought to the liver must pass through the hepatic capillaries before reaching the heart.

The foramen ovale does not close immediately after hatching, but does so in a few days; but, as soon as it does, all blood returned to the heart by the three venae cavae is emptied into the right auricle from which it is then forced into the right ventricle, thence through the pulmonary artery to the lungs, and back through the pulmonary veins to the left auricle, from which it is forced into the left ventricle, and finally through the systemic trunk. Such an entire separation of venous and arterial blood is called a **double circulation.**

XXXVIII.

THE COELOM AND THE MESENTERIES

In our account of the earthworm, the student was introduced to all higher forms of animals possessing a coelom or body-cavity. The chapter on the earthworm should be reviewed at this point.

Then, too, in the early part of our work on chick embryology, we have seen how the mesoderm divided into splanchnopleure or somatopleure and how the organs growing out from their respective beginnings pushed a layer of one of these coverings before them. And we have also seen how the chick embryo is quite similar to an animal which has had a ventral incision made along the midline and then had these two halves stretched over a yolk-sphere, so that its organs or portions of organs which developed from two primordia or beginnings, could later come together when the fusion of the ventral body walls produced a single organ of the two separated halves.

In adult birds and mammals, the coelom or body-cavity consists of three regions, known as **pericardial, pleural,** and **peritoneal.** The pleural region is paired, each half containing **one lung.** The other two chambers are unpaired. The pericardial region contains the **heart,** and the peritoneal contains all the **abdominal viscera.**

As the coelom arises by a splitting of the mesoderm, and the two halves of the chick are spread out over the yolk, the coelom is naturally a paired cavity, only becoming a single cavity when the ventral body walls of the embryo come together, and the ventral mesentery then disappears.

There are no segmental pouches in the chick coelom as there are in some of the lower vertebrates, though it cannot be said that this is unlike the lower forms, for, by the time the coelom appears in the chick, the pouches would already be broken through anyway, and have become connected.

As the mesoderm splits and the splanchnopleure and somatopleure extend out over nearly the entire yolk-sac, it is to be understood that much of this split mesoderm is **extra-embryonic.** This has already been described in an earlier chapter.

Here we are concerned with the **embryonic coelom.**

The portion of the embryonic coelom which gives rise to the three body-cavities mentioned above is marked off by a series of folds which separate the body of the embryo from the yolk. With the closure of the ventral body walls, the embryonic coelom becomes completely separated from the extra-embryonic, though in the yolk-stalk region it remains open much longer than in other portions (Fig. 281, C to G).

It is this same closure of the ventral body walls which also brings the two portions of the gut together ventrally. This causes the newly-closed gut to lie between the two layers of splanchnic mesoderm while the body-spaces on each side form a right and left coelomic chamber. In fact, there are **double layers** of mesoderm which enclose and support the gut. These double layered supports are called **mesenteries.** The dorsal mesentery remains as a continuous support—at least the greater portion of it does—but the ventral mesentery soon disappears, causing the right and left coelomic cavities to become confluent.

In the liver region, however, the ventral mesentery does not disappear (Fig. 293). The liver arose by a ventral outgrowth of the gut and extended into the ventral mesentery. As the liver grows ventrally from the digestive tract, there is a portion of the ventral mesentery lying dorsal to the liver, that is, between the liver and the gut. This persists as the **gastro-hepatic omentum** while the portion ventral to the liver is called the **ventral ligament** or the **falciform ligament.**

The dorsal mesentery persists, as stated, but has different names in different parts, i. e., **mesocolon,** where it supports the colon, **mesogaster,** where it supports the stomach, etc.

Septa grow out from the body wall to divide the body-cavity into the pericardial, pleural, and peritoneal chambers mentioned above.

XXXIX.

DEVELOPMENT OF THE FIFTH DAY

On this day the head and tail of the embryo have nearly come together by the great curving of the chick. The yolk is completely covered by the blastoderm, and the vascular area covers nearly two-thirds of the blastoderm.

THE LIMBS

It is during this day that the limb-buds increase considerably in size, and are marked off into a proximal rounded portion and an expanded distal region. It is in the expanded distal region that the digits can be seen to form in cartilage. The rounded proximal portion is slightly bent at the points where elbow and knee joints will be formed.

The elbow and knee-angles at first are directed almost straight out from the body, but on about the eighth day both fore and hind-limbs rotate until the elbow-joint points caudad, while the knee-joint points cephalad.

By the end of the tenth day, both pairs of appendages have their definite outlines, though feathers and nails are not yet formed.

Although the structures which are to become bones are first outlined in cartilage, they later become **ossified**. There are three well-formed digits in the expanded distal portion of the fore-limb at this time with a possible fourth in a rudimentary condition, while in the expanded distal portion of the hind-limb there are also three well-defined digits with two in a rudimentary condition.

The development of the bony vertebrae has already been discussed. Here it is well to state that the ribs develop as cartilaginous bars in the body wall of the chick. The ventral ends of these fuse ventrally, and after fusion, a portion of each of the fused ends separates from the remaining ribs from which they formed. It is this portion which has separated that becomes the **sternum**.

THE DEVELOPMENT OF THE SKULL

The skull is divided into two regions: (1) The **skull proper**, and (2) **the visceral skull**, this latter being that portion which has developed from the visceral arches.

THE SKULL PROPER

The notochord forms a sort of central portion around which the vertebrae form. The anterior end of the notochord serves a sort of similar function in the head region.

On each side of the notochord a sheet of cartilage develops. These two sheets are known as **parachordal plates** (Fig. 310). They form a

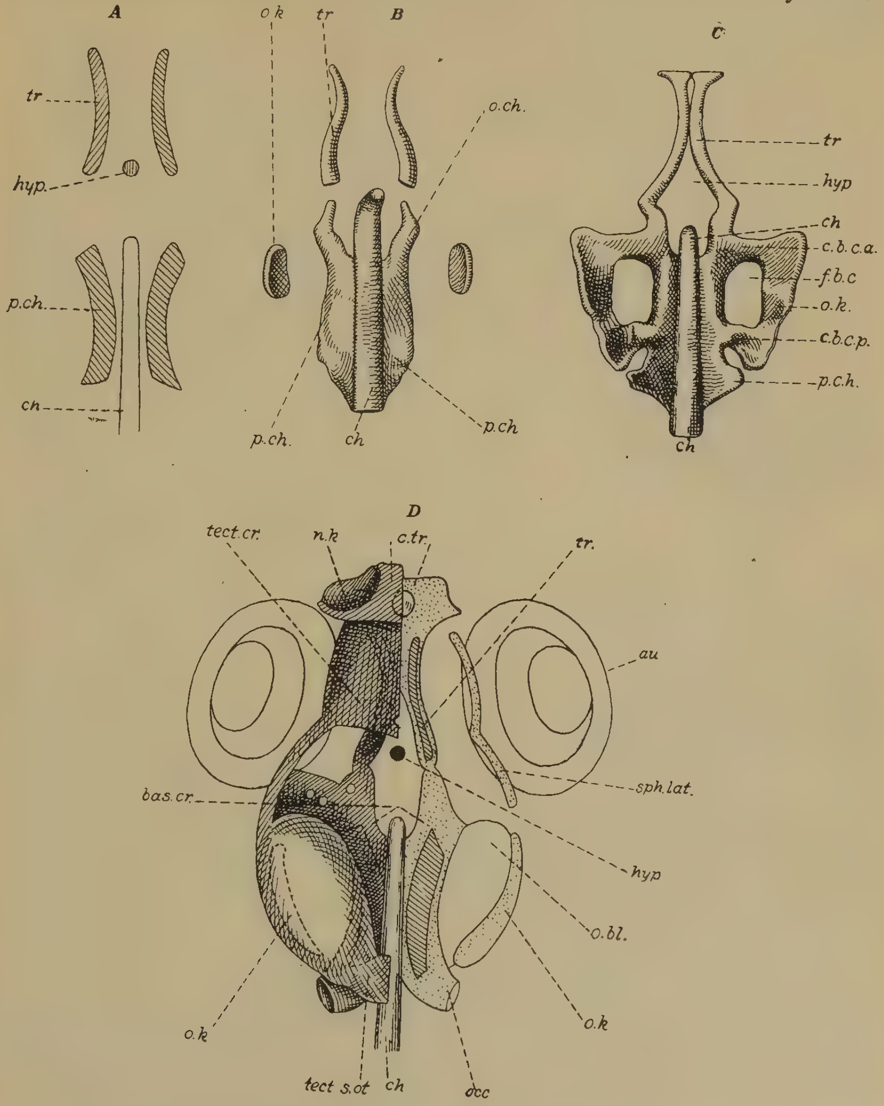


Fig. 310.

Diagrams of skull formation in Salmon. *A*, First anlage of cranium. *B*, *C*, *D*, successive stages in cranial development. Left half of *D* is an advance in development of right half. *au*, eye; *bas.cr.*, base of cranium; *c.b.c.a.*, *c.b.c.p.*, anterior and posterior basicapsular commissure (ascending process of palatoquadrate cartilage); *ch*, notochord; *c.tr*, trabecular cornu; *hyp*, opening in which hypophysis develops; *n.k.*, nasal capsule; *o.bl.*, and *f.b.c.*, fenestra basicapsularis; *o.k.*, ear capsule; *occ*, occipital region; *p.ch.*, parachordal plates; *sph.lat.*, lateral sphenoid; *tect.cr.*, roof of cranium; *tect.s.ot.*, Cartilaginous arch between otic capsules representing the cartilaginous roof of higher vertebrates (tectum synoticum); *tr.*, cranial trabeculae. (*A*, *D*, after Waskoboynikow; *B*, *C*, from Gaupp after Stöhr's model.)

floor for the mid and hind-brains. These plates then fuse both dorsally and ventrally around the notochord, and consequently enclose it. The fused plate is then known as the **basilar plate,** forming the floor of the hinder portion of the skull.

The **auditory capsules** which enclose the auditory organs form and fuse to the sides of the basilar plate. It is from growths of the basilar plate and the auditory capsules that the floor and occipital portions of the skull are formed.

The anterior portion of the skull is formed from two slender rods lying cephalad to the notochord, but which are in connection with the parachordal plates. These rods are known as **trabeculae cranii.**

The pituitary body lies between these trabeculae cranii, so that in fusing as they now do to form the **ethmoid plate,** the pituitary body comes to lie in the position where it will be found when we study Comparative Anatomy.

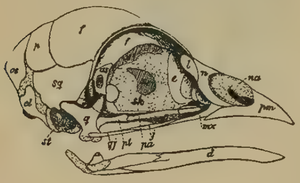


Fig. 311.

Profile view of 2-day chick-skull. *as*, alisphenoid; *d*, dentary; *e*, ethmoid; *f*, frontal; *l*, prefrontal; *mx*, maxillary; *n*, nasal; *ol*, lateral occipital; *os*, superior occipital; *pa*, palatine; *pm*, premaxillary; *pt*, pterygoid; *q*, quadrate; *qj*, quadrato-jugal; *na*, cartilaginous wall of nasal cavity; *sq*, squamosal; *st*, columella; *sk*, and *x*., cartilaginous portion of skull just becoming converted into bone. (Cartilage is stippled.) (After Boas.)

The ethmoid plate (Fig. 311) extends cephalad to the tip of the beak, and fuses anteriorly with the **olfactory capsules.**

The **interorbital septum** develops as a large vertical plate from the dorsal surface of the ethmoid plate, along the whole median line. It is quite common to speak of cartilaginous and membranous bones of the skull. This means only that some of the bones there formed (in fact, all these we have just been describing) were first preformed in cartilage, and then became bone, while the membranous bones were first cartilage, and then, by being placed where there was considerable stretching, they became quite thin membranes before they finally ossified.

The **membranous bones** form the roof of the skull, such, for example, as the parietals, frontals, etc.

THE VISCERAL SKULL

It will be remembered that the first visceral arch was also called the mandibular arch, because it is from this arch that the mandible or lower jaw is formed, and that the second visceral arch was known as the hyoid arch, because it is from this that the hyoid bone, or cartilage which supports the tongue, has developed. The parts of the skull which are thus developed from the visceral arches form the visceral skull.

THE HEART

It is during the fifth day that the **interventricular septum** is almost completed, fusing with the posterior edge of the septum which now develops in the truncus arteriosus. This latter septum is formed between the fourth and fifth pairs of aortic arches and follows a sort of spiral course caudally to where it joins the interventricular septum. It is the position and shape of these septa which cause the blood to course into the different channels as described for the fourth day.

Two sets of **semilunar valves** have now formed between the two divisions of the truncus arteriosus and the two ventricles into which they open. The heart continues growing, but it is not until about the twelfth day that the **interauricular septum** has almost completely closed, leaving only the **foramen ovale** as a small opening between the two auricles. The foramen ovale develops a little fold of membrane which some days after hatching closes the opening entirely.

The ventricles now become thickened to a very considerable extent. The auricles likewise thicken, but not to so great an extent as the ventricles. The ventricular thickenings on the inside of the heart form as an inward growth of ridges which are called **trabeculae carnae.** They are really separate muscle-bundles which help to open and close the valves.

On the sixth and seventh day the distinctly bird-like characteristics appear. Up to this time the beginner cannot tell the difference between a chick embryo and that of practically any other one of the higher vertebrates.

The nasal region now begins to lengthen and the fore-limbs will be seen to develop into wings.

The allantois has become very large and contains a considerable amount of fluid.

The omphalomesenteric arteries and veins now pass from the body of the embryo as single vessels. The yolk, though seemingly as large as before, is quite liquid in form.

The flexion of the body is less marked than before, while the head is not so large in proportion to the remainder of the body as formerly.

The cerebral hemispheres can be seen quite plainly, as well as the beginnings of the tongue-bud.

On the next three or four days the little sac-like regions in which the feathers develop make their appearance as protrusions from the surface, especially on the dorsal side of the chick, while a chalky patch at the tip of the nose marks the beginning of the horny beak. The yolk has become wrinkled and flabby.

After the eleventh day, the abdominal walls become firmer and the intestines are enclosed in the peritoneal cavity. The body is now complete except for the narrow stalks of the umbilicus and yolk-sac. The amniotic fluid tends to disappear, making the amnion less prominent.

By the thirteenth day the feathers are well distributed over the entire body, although they do not break through their sacs until about the nineteenth day, by which time they are approximately an inch in length.

On the thirteenth day the nails and scales appear on the toes, and by the sixteenth day nails, scales and beak are firm and well developed. On this day also the cartilaginous skeleton completes its growth, and various **centers of ossification** make their appearance.

By the sixteenth day the white of the egg has disappeared and the mesoderm has divided completely into the splanchnopleure and somatopleure all the way around the yolk.

On the nineteenth day the remains of the yolk are drawn into the body cavity of the embryo.

The embryo begins its development originally by lying with its axis transverse to the long axis of the egg, but by the fourteenth day it turns so that its head is toward the air space at the larger end of the egg, and at about the twentieth day the chick's beak is pushed through the inner covering of the air space so that it can now begin using its lungs. It is at this time that the pulmonary circulation begins. The blood stops flowing into the umbilical vessels, and the allantois consequently shrivels up and is left inside the shell as the chick pecks its way out.

XL.

THE EMBRYOLOGY OF THE FROG

THE GENERAL EMBRYOLOGY OF THE TADPOLE AS COMPARED WITH THAT OF THE CHICK

As in our study of the embryology of the chick, it is essential that the student again read the chapters on mitosis, fertilization, and the summary on embryology, and then go over each system in the developing chick corresponding to the system he may be studying in the frog, for only in this way can the comparison of the developmental processes be understood.

After this has been done, the following groups of **Craniata** must be kept clearly in mind to make clear the various embryological relationships which must be referred to, not only in the study of embryology, but also in Comparative Anatomy.

CLASSIFICATION OF CHORDATA

(After Newman)

Sub-Phylum I. **Cephalochordata (Adelochorda)**, (Fig. 312).

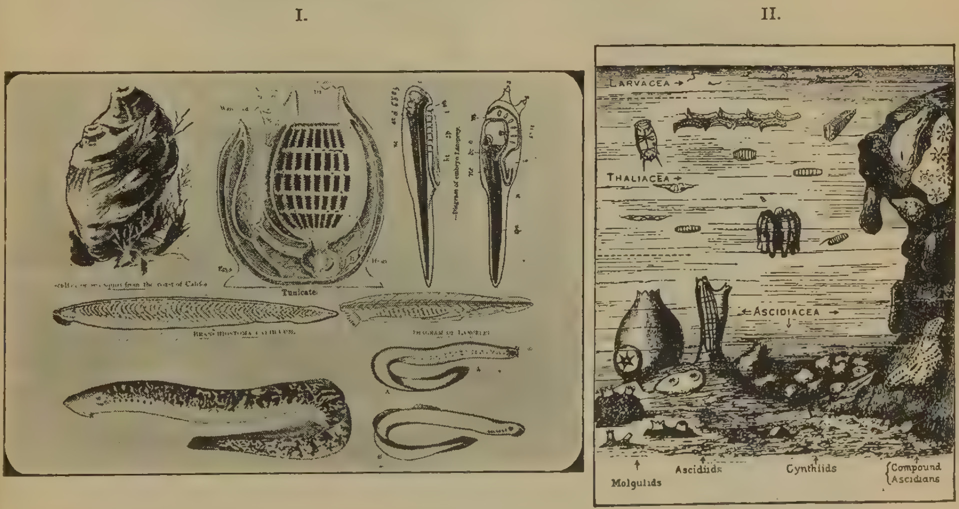


Fig. 312.

I. Examples of *Amphioxus* (*Branchiostoma* and *Lancelet*), *Tunicates* (First two upper figures), Lamprey (The large, lower, left-hand figure-adult; and the embryo lamprey, usually called *Ammocoetes*—2 upper right-hand figures), and the *Hagfish* (2 lower right-hand figures).

II. Sketch of chief kinds of *Urochordata* showing distribution in sea. Dotted lines on left indicate life-zones. The surface is called the pelagic zone. (From Herdman.)

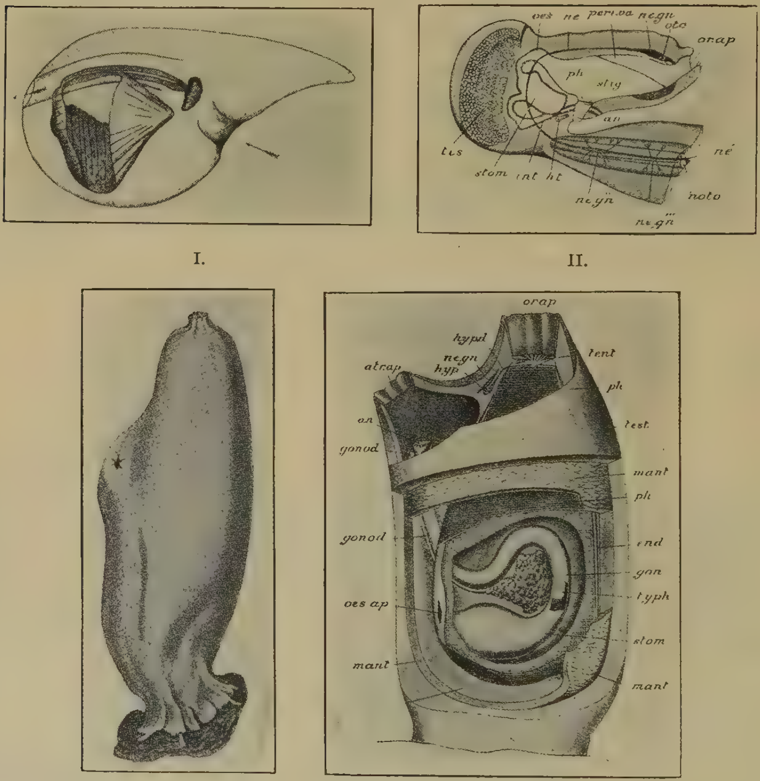
This includes but a single family of fish-like creatures, of which there are about twelve species. The type form is **Amphioxus** more correctly known as **Branchiostoma**).

Sub-Phylum II. **Urochordata** (Figs. 312, 313).

Order 1. **Larvacea (Appendicularia)**, free-swimming forms with permanent tail.

Order 2. **Ascidiacea (Tunicates or Sea-Squirts)**, fixed forms without tail in the adult.

Order 3. **Thaliacea (Salpians)**, free-swimming forms without tail in the adult.



I. II.

III. IV.

Fig. 313.
UROCHORDATA.

I. *Oikopleura* in 'house'. The arrow shows course of current.

II. Diagram of *Appendicularia* from the right side. *an*, anus; *ht*, heart; *int*, intestine, *ne*, nerve; *ne'*, caudal portion of nerve; *ne.gn'*, principal nerve ganglion; *ne.gn''*., *ne.gn'''*., first two ganglia of tail nerve; *noto.*, notochord; *oes.*, oesophagus; *or.ap.*, oral aperture; *oto.* otocyst (statocyst); *peri.bd.*, peri-pharyngeal band; *ph.*, pharynx; *tes.*, testis; *stig.*, one of the stigmata; *stom.* stomach. (After Herdman.)

III. and IV. *Ascidia.* Entire animal as seen from the right side and dissection from the same side. *an*, anus; *atr.ap*, atrial aperture; *end*, endostyle; *gon*, gonad; *gonad*, gonoduct; *hyp*, neural gland; *hyp.d*, duct of neural gland; *mant*, mantle; *ne.gn.* nerve-ganglion; *oes ap*, aperture of oesophagus; *or ap*, oral aperture; *ph*, pharynx; *stom*, stomach; *tent*, tenacles; *test*, testes. (After Herdman.)

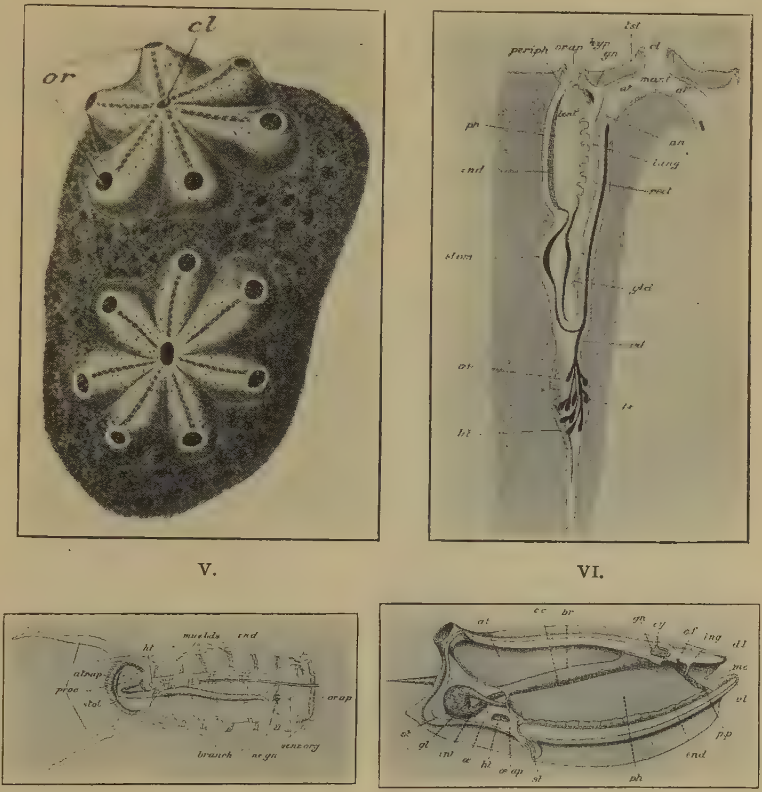
Sub-Phylum III. **Hemichordata** (Fig. 314).

Order 1. **Enteropneusta**, including worm-like forms such as **Balanoglossus**.

Order 2. **Pterobranchiata,** sessile, tube-dwelling forms—**Cephalodiscus** and **Rhabdopleura.**

Order 3. **Phoronidia,** tubicolous forms—**Phoronis** (Fig. 199).

Sub-Phylum IV. **Vertebrata** (Craniata).



V. VI.

VII. VIII.

Fig. 313.

V. *Botryllus violaceus.*

VI. *Composite Ascidian.* Diagram of an individual member of a colony of composite Ascidians. The zooids are in pairs and seen in vertical section. *an,* anus; *at,* atrium; *at',* atrium of adjoining zooid; *cl,* cloaca common to both zooids; *end,* endostyle; *gld,* digestive gland; *gn,* nerve ganglion; *ht,* heart; *hyp,* neural gland; *lang,* languets; *mant,* mantle; *or.ap,* oral aperture; *ov,* ovary; *periph,* peripharyngeal band; *ph,* pharynx; *rect,* rectum; *stom,* stomach; *te,* testis; *tent,* tentacles; *tst,* test or common gelatinous mass in which individuals are imbedded; *v.d,* vas deferens (*V,* after Mile-Edwards; *VI,* after Herdman.)

VII. *Salpa democratica,* asexual form, ventral view, and VIII lateral view in section. *at,* atrial cavity; *atr.ap,* atrial aperture; *br,* branchia; *branch,* dorsal lamina; *c.c,* ciliated crests on edge of branchia; *c.f,* ciliated funnel; *d.l,* dorsal lip; *end,* endostyle; *ey,* eye; *gl,* digestive gland; *gn,* ganglion; *ht,* heart; *int,* intestine; *lng,* languet; *mo,* mouth; *mus.bds,* muscular bands; *ne.gn,* nerve-ganglion; *œ,* oesophagus; *oe.ap,* and *or.ap,* apertures of oesophagus and mouth; *ph,* pharynx; *pp,* peripharyngeal band; *proc,* processes at posterior end; *sens.org,* sensory organ; *st,* and *stol,* stolon; *st,* on left, stomach; *v.l,* ventral lip. (*VII,* after Vogt and Jung, *VIII,* after Delage and Herouard.)

Order 1. **Cyclostomata** (round mouth eels), such as hagfish and Lampreys (Fig. 312).

Order 2. **Pisces** (true fish with jaws).

Order 3. **Amphibia** (vertebrates with aquatic larvae, but usually air breathing in the adult condition), (Fig. 315).

Order 4. **Reptilia** (cold-blooded, air-breathing vertebrates).

Order 5. **Aves** (birds, feathered vertebrates).

Order 6. **Mammalia** (beasts or quadrupeds).

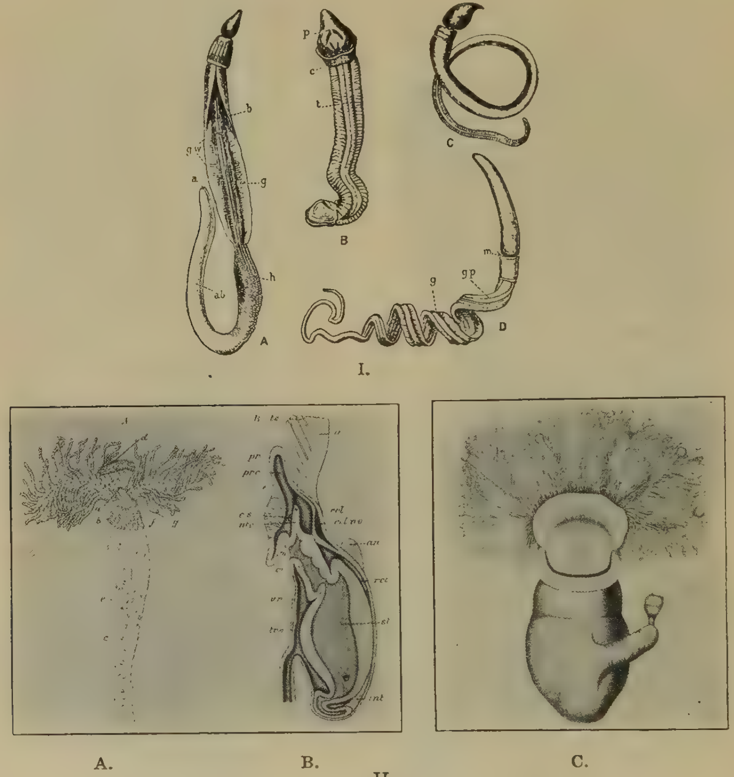


Fig. 314.
HEMICHORDATA.

I. Various types of *Enteropneusta* which are relatives of *Balanoglossus*. *A*, *Balanoglossus clavigerus*; *B*, *Glandiceps hacksi*; *C*, *Schizocardium brasiliense*; *D*, *Dolichoglossus kowalevskii*; *a*, anus; *ab*, abdominal and caudal regions; *b*, branchial region; *c*, collar; *g*, genital region; *gp*, gill-pore or branchial cleft; *gn*, genital wing; *h*, hepatic region; *m*, position of mouth; *p*, proboscis; *t*, trunk. (From Newman, *A*, *B*, *C*, after Spengel, *D*, Bateson.)

II. *A* and *B* *Rhabdopleura*, *C* *Cephalodiscus dodecalophus*. *A* and *C*, entire animals. *B*, diagram of median longitudinal section of *A*. *A*, *a*, mouth; *b*, anus; *c*, stalk of zooid; *d*, proboscis; *e*, intestine; *f*, anterior region of trunk; *g*, one of the tentacles. (After Ray Lankester.) *B*, *a*, arm; *an*, anal prominence; *col*, collar; *col.ne*, collar nerve, *c.s*, cardiac sac; *int*, intestine; *m*, mouth; *ntc*, notochord; *oe*, oesophagus; *pr*, proboscis; *pr.c*, proboscis-coelom; *rct*, rectum; *st*, stomach; *te*, tentacles; *tr.c*, trunk-coelom; *v.n*, ventral nerve. (B, after Schepotieff; C, after McIntosh.)

The frog is usually considered a transitional form separating the lower from the higher craniata both embryologically and anatomically. And although the craniates vary considerably among themselves, the frog has enough in common with all such variations to make it a norm or standard type for constant and valid reference, both as to anatomy and development. The adoption of a standard makes an understanding possible of any special modifications one may find.

Then, so much work has been done in this field that a thorough understanding of the embryology of the frog is essential to anyone who wishes to do advanced work in the zoölogical sciences.

Just as there are various groups of birds with different hatching periods, so different species of frogs also vary as to the length of time the embryo requires before being able to emerge from the egg. But, unlike the birds, the frog passes through a process of **metamorphosis,** which simply means that even after the embryo's emergence from the egg, it does not have the adult form, but must pass through still further changes before becoming a full-fledged frog. In the frog the form that is assumed at the time of hatching and which later changes on arrival at adult life, is called the **tadpole** stage.

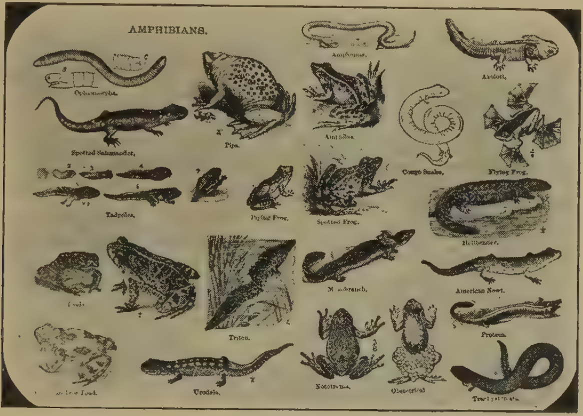


Fig. 315.

Examples of tailed and tailless Amphibia.

Temperature has much to do with both the rapidity with which a frog's egg develops, and with which the tadpole develops into an adult frog. This, however, is not unlike the hen's egg, for, it will be remembered that after the hen's egg was fertilized and the embryo had already begun to develop (before the egg has been laid), such an egg could be placed in a moderately cool place for many days, which would result in all development ceasing. If the egg is then placed under a hen, or in an incubator, the embryo again begins to develop.

We shall arrange our study of the frog under two headings: **First,** the **true embryonic period.** This extends from the time the egg is fertilized through **blastulation** and **gastrulation.** During this time the **germ layers** as well as the larval and tadpole organs form. This period extends up to the time the tadpole emerges from the egg.

Second, the **larval period,** from the time of hatching to the time the **legs** are formed, the tail is thrown off, and the animal has become a full-fledged frog with all its various organs and the form that it is to retain throughout adult life.

To grasp fully that which follows, it is necessary to review the account of the reproductive organs in the chapter on the frog in the early part of this book.

As the sperm from the male frog never enter the female body, the egg must be fertilized after it has been laid. This is quite different from fertilization in the hen. During the breeding season, as the eggs are squeezed from the female, the male passes over the eggs and deposits his sperm upon them. The fertilized eggs begin to divide almost immediately, and within approximately thirty-six hours the blastula stage has been reached. In about six days, when the embryo is five millimeters in length, there is already a twitching within the egg, showing that life is present, and within two weeks after fertilization the embryo wriggles its way out of the surrounding jelly and becomes a free-living **larva** or **tadpole.** This is the end of the true embryonic period.

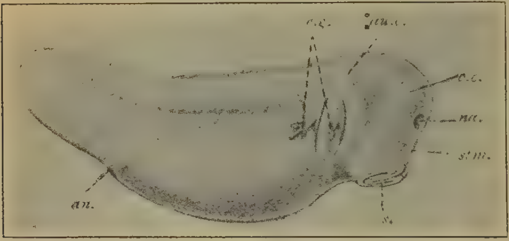


Fig 316.

A frog embryo at the stage of hatching. *an.*, Proctodæum; *au.c.*, slight swelling over the rudiment of the ear; *e.g.*, external gills on gill arches; *na.*, invagination to form nasal capsule; *o.c.*, slight swelling over the rudiment of eye; *s.*, sucker; *stm.*, stomodæum (invagination which will form the mouth. (After Borradaile.)

If the temperature is greater than normal, such as it usually is in the laboratory, then the larvae may hatch in five days. In either case, however, **suckers** (Figs. 316, 317, 318) are formed in the head of a tadpole by which it attaches itself to a jelly-like substance surrounding the eggs although it may attach itself to other objects in the water as well. Sometimes the tadpoles will even fall to the bottom of the water and lie there.

As the **mouth opening** does not form until two to five days after hatching, the tadpole naturally cannot take in any food from the outside, and so is still dependent upon the yolk, still undigested, within its body.

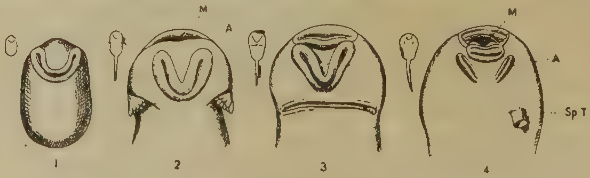


Fig. 317.

Four stages of the development of the adhesive apparatus (suckers) of *Bufo vulgaris; A*, suckers; *M*, mouth; *Sp T*, spiracular tube. In 3 the gills are almost completely hidden by the united right and left opercular folds.

The small outline figures indicate the shape and approximate size of the tadpoles. (After Thiele.)

As soon as the tadpole begins to take in food from the outside, the suckers deteriorate and disappear. From this time on the tadpoles are very active They feed on almost any plant or animal debris, and in the laboratory will thrive on a diet of cereals. As the egg is dependent upon temperature for its rate of speed in developing, so the rate of speed at which the tadpole grows is dependent upon the **quantity** of food it obtains.

External gills develop shortly after hatching, being used as **respiratory organs.** These disappear as soon as the mouth opens, and the **true internal gills** are formed. When the true gills form, they are protected by a cover called the **operculum.** The portion underneath the operculum remains connected with the outside by only a **single pore** on the left side, known as a **spiracle.** The limb-buds appear normally at about four or five weeks, although in the laboratory at a higher temperature, much sooner. The anterior pair develop within the opercular cavity, and consequently cannot be seen from the outside. The posterior develop, one on each side of the cloaca a little later, and become quite large and jointed by the end of the second month.

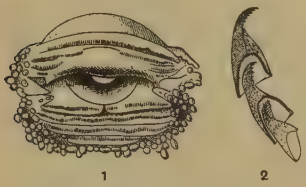


Fig. 318.

1, Front view of the mouth of a tadpole of *Rana temporaria* showing the transverse rows of tiny horny teeth; 2, Three successive horny teeth highly magnified. (After Gutzeit.)

In the meantime the lungs have been growing and the young tadpole comes to the surface of the water to expel small bubbles of air and to take in a fresh supply. In the common species of frogs, metamorphosis begins at about the end of the third month. It is at this time that the tadpole ceases feeding, and the outer layer of skin, as well as the horny jaws (Fig. 318), are thrown off. The lips shrink, the mouth is no longer suctoreal, and becomes much wider, while the tongue increases in size. The eyes also become prominent. The fore-limbs appear, the left one pushing through the opening of the gill chamber, while the right pushes its way through the opercular fold on that side, leaving a ragged hole. The stomach and liver enlarge, while the intestine becomes shorter and smaller in diameter than before, and the animal becomes carnivorous. The gill-clefts close and many changes occur in the blood vessels due to the change in the animal's mode of breathing. The bladder is formed, the kidneys undergo changes, and there is a definite sexual differentiation. The tail shortens and is finally lost as the hind legs continue to lengthen.

If, however, the water has been particularly cold, the metamorphosis may be put off until the following spring; in fact, it seems normal with some species to wait even longer than this, namely, as long as two years, and sometimes three (Necturus) before the adult form is assumed.

If one thinks of the hen's egg being laid without the normal shell, such a shell-less egg would be somewhat akin to the frog's egg. Here the yolk is a rather blackened mass with a jelly-like substance surrounding it, similar to the white of the hen's egg, but without a solid shell. Great masses of the eggs are found in one place, appearing very much as though dozens of hen's eggs were broken, but with the yolks entire. The eggs vary in different species from one and five-tenths millimeters in diameter to twice that size. A little over half of the egg is a dense black due to the pigment granules contained therein, while the remainder is rather white, although again, in different species the quantity of pigment may vary greatly. The darker portion is commonly known as the **animal pole**, and the lighter as the **vegetal pole**.

There are three membranes covering the egg: **Primary.** That known as the **vitelline membrane.** This can sometimes be distinguished from the pigmented substance lying directly beneath it, although some writers deny that it exists at all.

The **secondary membrane** (sometimes called the **chorion**) is a rather thin but tough layer secreted from the follicle cells of the ovaries.

The **tertiary membrane** is a thick, jelly-like layer derived from the walls of the oviduct, lying close to the chorion, first as a dense layer, but later as it enlarges it becomes quite clear.

It will be remembered that the yolk granules were quite evenly distributed in the yolk of the hen's egg and that the embryo developed upon the yolk. In the frog, however, the **deutoplasm** or food part of the yolk all lies at one end—the vegetal pole. Frog's eggs are therefore said to be **telolecithal.**

The nucleus lies in the animal pole and has already commenced to divide by the time the egg is laid. In fact, it is already in the metaphase of the **second polar division** at that time. The first polar body has been thrown out, and can be seen as a very tiny light spot in the flattened area of the upper pole.

As the reproductive organs of the adult have just been reviewed, we shall not again discuss them here, but the **development of these organs** will be taken up individually at a little later period. The general development of egg and sperm are quite like that which occurs in the germ cells of the chick.

FERTILIZATION

The sperm drills its way through the thin jelly of the chorion and normally enters the egg substance in the pigmented region. The point of entry is a meridian, passing through both poles of the egg. The meridian which passes through the animal and vegetal poles of the egg, as well as through the point where the sperm enters, is called the **fertilization meridian.** Only one sperm normally enters the egg. Polyspermy is not, however, rare, but as far as we know, always results in some abnormal development when it takes place.

It will be remembered that after one-half of the chromosome material of the nucleus of the egg has been thrown out by the two polar divisions, the nucleus which then contains **one-half the normal number of chromosomes** is called the **female pro-nucleus.** The head of the sperm (which also has only half of the normal number of chromosomes) now enters the egg and leaves a trail of pigment behind it. This sperm, after entry into the egg, becomes the **male pro-nucleus.** The head of the sperm makes its way directly to the female pro-nucleus. The tail of the sperm is thrown off although both tail and midpiece enter the **penetration path** (Fig. 319). The head and midpiece after traveling for some distance in the egg, rotate so that the midpiece is placed in advance of the head. The midpiece then begins to dissolve and to form a typical nucleus with an opening within which is called a **vesicle.** The sperm then changes its course, and moves toward the point where male and female pro-nuclei will unite, unless, of course, the penetration path has already led in that direction. The path made by the changing of direction of the head of the sperm is called the **copulation path** (Fig. 319). This path is also marked by a trail of pigment as the head of the sperm passes through the cytoplasm to reach the female pro-nucleus.

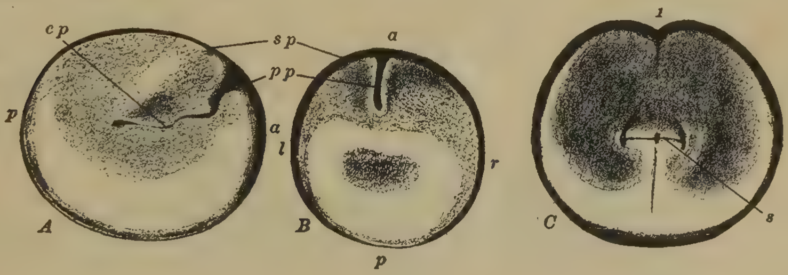


Fig. 319.

Sections through the egg of *R. fusca*, showing penetration and copulation paths, and the symmetry of the first cleavage plane. *A.* Sagittal section through the egg before the appearance of the first cleavage; *B.* Frontal section of the same stage as *A*, showing the symmetrical distribution of the egg material. *C.* Frontal section through egg in two-cell stage, showing the symmetry of the egg; the penetration path is not shown. *a*, Anterior; *cp*, copulation path; *l*, left; *p*, posterior; *pp*, penetration path; *r*, right; *s*, remains of first cleavage spindle; *sp*, superficial pigment; *1*, first cleavage furrow. (After O. Schultze.)

After the sperm has entered the egg, some of the fluid from the egg proper is withdrawn into a space **between the egg itself and the chorion.** This is known as a **perivitelline space.** The egg can thus rotate within its membrane. From this time onward the pigmented pole is always uppermost. In unfertilized eggs, the membranes are more or less adherent. The jelly-like covering of the egg absorbs considerable fluid and swells up in about a minute after the egg touches water. A close observation of the jelly shows that it is made up of various layers, whose function is not only to protect the egg from chemical and mechanical injuries, and from being eaten by other organisms, but also to elevate the temperature of the egg. They accomplish this latter by being transparent spheres which condense the heat rays from the sun and at the same time check the radiation from the egg itself.

MATURATION

It has been stated that by the time the sperm enters the egg, the second polar division has already taken place, or rather, the metaphase of the **second division is in the process** of taking place. This division is completed rapidly and cuts off the second polar body in about thirty minutes after the sperm enters the egg. The second polar body is either the same size or smaller than the first. The egg-nucleus then assumes its normal form. The polar bodies are often seen floating about in the perivitelline space.

The male and female pro-nuclei now move toward the center of the egg and meet in the usual manner. The female pro-nucleus does not leave any pigment in its trail as does the male. The sperm centrosome and centrosphere divide to form the poles of a small but typical cleavage figure, which is always located toward the animal pole, never in the center of the egg.

Immediately after fertilization, there is a **streaming of the formative protoplasm** upward, and the deutoplasm downward, so that the animal pole obtains practically no yolk, and the vegetal pole is composed almost entirely of it. At this time also, the pigment granules directly opposite the point where the sperm enters the egg are carried away, which leaves a somewhat crescent shaped lighter area. This crescentic area extends from half to two-thirds the distance around the egg, and is known as **the gray crescent** (Fig. 320). This moving of the heavier portion to one side changes the specific gravity of the egg so that the portion possessing least weight lies uppermost and close to the gray crescent just opposite the point of entry of the sperm.

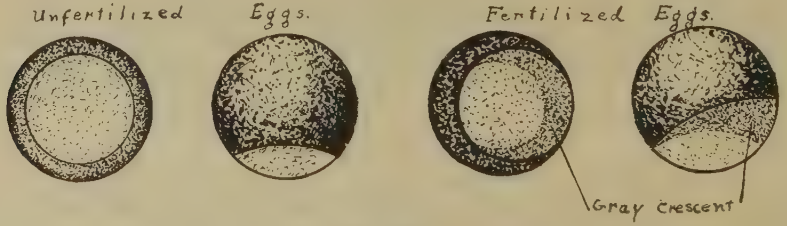

Unfertilized Eggs.
Fertilized Eggs.
Gray crescent

Fig. 320.

Frog's eggs showing formation of gray crescent from side and from vegetal pole. The animal pole is heavily pigmented.

In about an hour and a half after the entrance of the sperm, in **Rana fusca**, according to Bracheti, the egg has arranged itself in the manner described, and is now ready for the first cleavage. A vertical plane is drawn through the point where the sperm enters the egg and passes over the top of the egg through the egg-crescent. This becomes the midline, on both sides of which the bilateral embryo is to develop.

There are three distinct substances of varying specific gravity in the frog's egg, namely, **protoplasm, pigment,** and **deutoplasm,** and these do not arrange themselves in the manner described until **after fertilization,** so that we may say that bilateral symmetry in the frog's egg is **potential but not actual** until **after fertilization and the rearrangement of these three different substances.**

The original cleavage plane lies at right angles to the **egg axis,** but not at right angles to what is to become the axis of the embryo itself. There is no direct relation between the plane of the first furrow in cleavage and the fertilization meridian. The midline of the developing embryo and the penetration path of the sperm normally correspond to a vertical plane known as a **gravitational plane,** drawn through the egg after the particles of protoplasm and deutoplasm have rearranged themselves according to gravity, and all of these correspond to the first cleavage furrow, though many variations of this occur.

THE FORMATION OF THE BLASTULA

One of the chief reasons for studying the embryology of the chick before that of the frog is that the **three germ layers** of the chick are more readily seen. The frog's egg divides into two portions, then into four, eight, etc., quite like the hen's egg, and by the time there are eight cells present, the four cells in the region of the animal pole are found

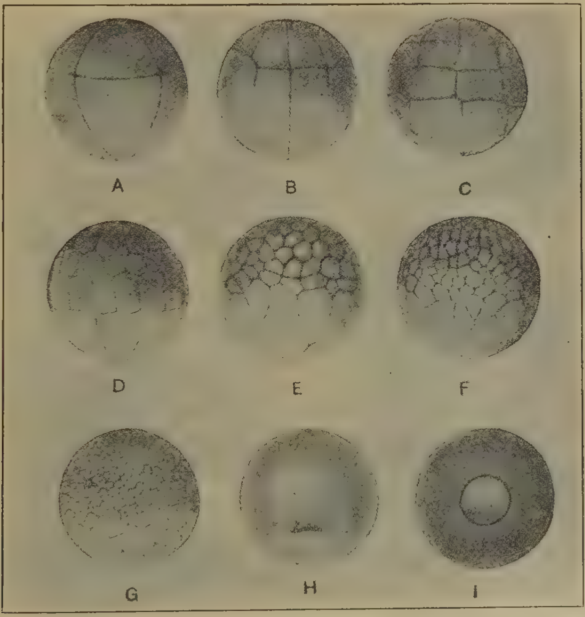
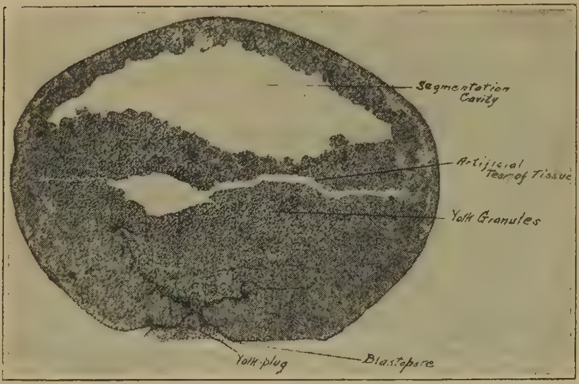
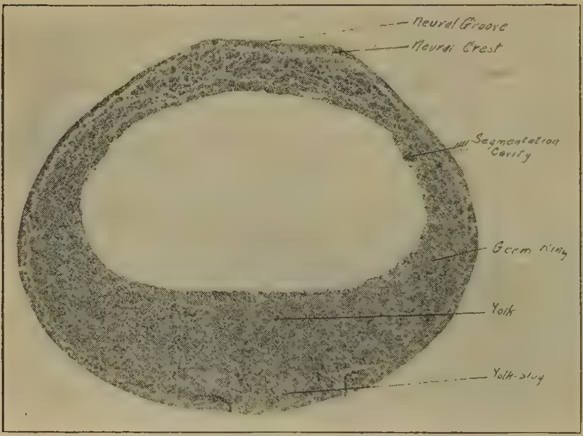


Fig. 321.

Cleavage of the frog's egg. *A* Eight-cell stage; *B*, beginning of sixteen-cell stage; *C*, thirty-two-cell stage; *D*, forty-eight-cell stage (more regular than usual); *E*, *F*, *G*, later stages; *H*, *I*, formation of blastopore. The central light area in *I* is the yolk-plug while the ring which encases the yolk-plug is the margin of the blastopore. (After Morgan.)

to be smaller than the four in the region of the vegetal pole. The smaller ones are called **micromeres** and the larger ones **macromeres.** The micromeres, after the fifth cleavage begins, divide more rapidly than do the macromeres. By a continually more rapid growth of this kind, the smaller animal cells soon almost surround the vegetal or yolk substance. As the yolk becomes surrounded more and more, there is a somewhat central region where the yolk can still be seen from the exterior. This portion of the yolk is called the **yolk-plug,** while the margin of darker animal cells immediately surrounding the yolk-plug is called the **blastopore** (Figs. 321, 323).





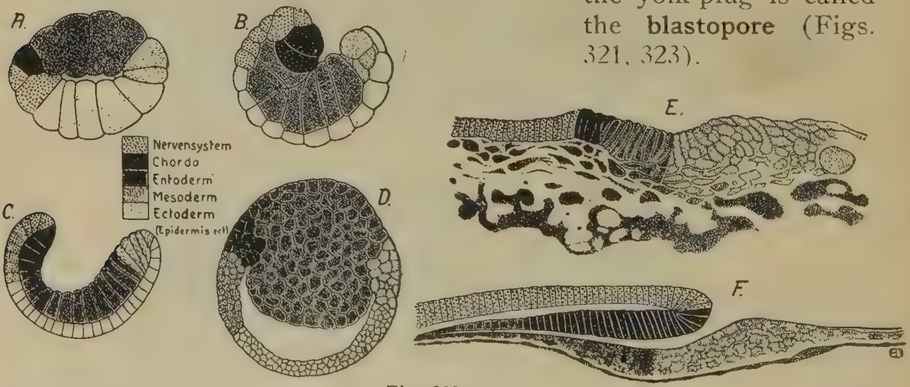


Fig. 322.

First two figures, photographs of Frog Blastulas. *A* to *F*, median sections through Blastulas and Gastrulas of *A*, *Cynthia bipartia* with 64 cells (this is a member of the tunicates). *B*, Gastrula of *Ciona intestinalis* (also a tunicate). *C*, Gastrula of *Amphioxus; D*, Blastula of *Axolotl* (Mexican salamander which breeds in the larval stage); *E*, Gastrula of an early stage of Turtle (*Chelonia caouana*), *F*, Gastrula of a later reptilian stage (in the *Gecko*). *A* to *F* after Rabl and Van Beneden.)

The fact that the entire yolk comes to lie **within** the blastoderm causes much of the growth process to be hidden from view. In fact, Professor Johnstone of Cambridge University suggests that the frog embryo may not have the three regular germ layers at all. We think they are present, although pressed together so closely that it is practically impossible to distinguish them.

A slight separation of the darker cell layer in the yolk-plug region leaves an opening called the **segmentation cavity** or **blastocoele** (Figs. 322, 323). The portion of the **pigmented layer** which has separated from the yolk-plug will now be known as the **dorsal lip of the blastopore** (Fig. 323).

The segmentation cavity forms near the animal pole. The entire blastula, however, is not much larger than the original egg because, although there are now thirty-two to sixty-four cells definitely formed, these have been formed by constant cell division **without much growth** after dividing. The roof and walls of the segmentation cavity are, therefore, composed of the external pigmented animal cells. These cells are of different shapes and sizes, rather irregular and loosely arranged, and really divided into two sheets, one lining the blastocoele, and the other forming the true outer layer of the blastula. It will thus be seen that

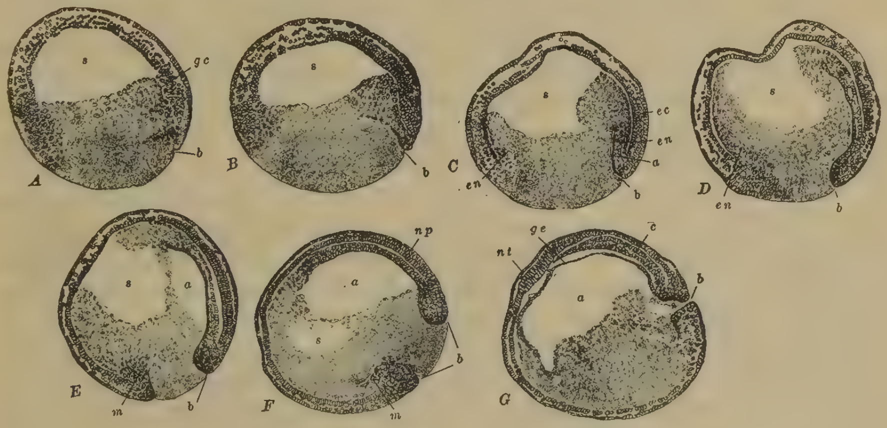


Fig. 323.

Median sagittal sections through a series of gastrulas of the frog (*R. temporaria*). The figures illustrate the change in position of the whole gastrula, as well as the phenomena of gastrulation proper. *A.* Commencement of gastrulation; earliest appearance of the dorsal lip of the blastopore. Internally the gastrular cleavage is indicated. *B.* Invagination more pronounced; beginning of epiboly. *C.* Invagination, epiboly and involution in progress. The gastrular cleavage is now indicated on the side opposite the blastopore. Rotation of the gastrula. *D.* Just before the ventral lip of the blastopore reaches the median line. The indentation of the wall of the segmentation cavity is an artifact. *E.* Blastopore circular and filled with yolk plug. Gastrula beginning to rotate back to its original position. Peristomial mesoderm differentiating. *F.* Segmentation cavity nearly obliterated. Neural plate established. *G.* Gastrulation completed. *a*, Archenteron; *b*, blastopore; *c*, rudiment of notochord; *ec*, ectoderm; *en*, endoderm; *gc*, gastrular cleavage; *ge*, gut endoderm; *m*, peristomial mesoderm; *np*, neural plate; *nt*, transverse neural ridge; *s*, segmentation cavity or blastocœle. (After Brachet.)

the frog blastula is not made up of a single layer of cells, but of a **double layer of animal cells.** This double layer is the **ectoderm.** The floor of the blastocoele is made up of the large vegetal cells.

As the pigmented animal micromeres divide more rapidly from now on, they naturally must grow toward the equator. This causes a thinning of the roof, but a thickening of the walls of the segmentation cavity. The equator of the blastula seems to be the region in which the cells multiply most rapidly, and this equatorial region is called the **germ-ring** or **growth zone** (Fig. 324).

At the same time the germ-ring begins its rapid multiplication of cells, the gray crescent extends downward rather rapidly. This region is to become the **posterior** or **caudal** side of the embryo. The germ-ring from now on continues extending beyond the equator into the vegetal region until it lies approximately half way between the equator and vegetal pole. This growing of the germ-ring pushes the yolk more and more within the overgrowing animal cells, as already mentioned. The yolk thus being pushed within, naturally forces the floor of the segmentation cavity into a convex arch.

This is considered the **end of blastulation** in the frog's egg.

THE FORMATION OF THE GASTRULA

We have at this point, then: most of the yolk withdrawn within the overgrowing animal cells, two layers of which form the outer covering of the blastula at the animal pole; a segmentation cavity with its floor convexly arched, and a definite antero-posterior differentiation, the posterior side being marked by the gray crescent.

The development of the gastrula begins just beneath the posterior lip of the blastopore by a groove which forms directly between the animal cells and the yolk cells (Fig. 323, A, gc). The groove itself is lined by both kinds of cells on its opposite faces. We know from the development which takes place later that this groove is the real beginning of **invagination.** The groove itself becomes the **archenteron** or **primitive intestinal tract** (Fig. 323, C, E, F, G, a). The upper lip of this groove is the **rim of the blastopore** (Fig. 323, b). The animal cells become the **ectoderm** and the yolk cells become **entoderm.**

As the yolk is pushed within the blastula it causes a narrow groove to form in the region of the blastocoele, which separates the rising floor from the remaining yolk. This groove finally becomes a definite narrow slit, which splits off the ectoderm and entoderm at the point of invagination. The original groove is known as the **gastrular groove,** and the splitting off into ectoderm and entoderm is called **gastrular cleavage** (Fig. 323, A, gc). This gastrular cleavage extends from the dorsal lip of the blastopore entirely around the gastrula to the opposite side from where invagination takes place.

In the invagination area, a definite tongue of ectodermal cells pushes inward (Fig. 323, C, en) and joins directly with the inner yolk cells to form the entoderm. Due to their position, the inner yolk cells are also entoderm, although they do not form by a true invagination.

Viewing the entire egg externally during the process of gastrulation, we may consider the germ-ring as something like a rubber band placed about an ordinary ball in an equatorial plane. By sliding the rubber band off the ball toward one side, we may understand how the germ-ring brings its lateral region together in the mid-rim in the posterior or caudal region. This coming together not only pushes the underlying cells within, but causes the entoderm to extend further inward and thus increases the cortical extent of the archenteron.

We, therefore, have the first invagination of the pigmented cells forming the dorsal lip of the blastopore; the invagination then extends laterally in both directions to form the **lateral lips of the blastopore**; and finally the process of invagination continues around to the side of the gastrula, practically to a point almost opposite to where it began, and where the **ventral lip of the blastopore** is formed. This completes the **entire blastopore.** After the yolk plug has disappeared within the gastrula, the blastopore remains a narrow, elongated slit connected with the archenteron.

The method by which the blastopore grows by **concrescence** and forms the **primitive streak** has already been described in the chick, a re-reading of which should be done at this point. Comparisons should constantly be made between the development of frog and chick embryos.

It will be noted from what has been said that gastrulation is not so much formed by invagination in the frog as it is by a **delamination** within the gastrula itself.

In fact, among the higher chordates, invagination is sometimes entirely lacking, so that gastrulation may be accompanied by either **involution,** such as takes place in the chick, or by **epiboly,** which occurs to some extent in the frog, and by **delamination,** a process just described.

At this point Figure 325 must be studied to understand the varying changes of positions of the blastopore brought about by the rotation of the egg. It is also to be remembered that the blastopore marks the caudal extremity of the embryo.

The two-layered stage in the frog is of very short duration.

In the inner region, where the germ-ring and the yolk-cells which line the blastocoele are continuous, there are **transitional cells** which are to become the **mesoderm** (Fig. 324, m). These cells are continuous with ectoderm on one side and entoderm or yolk-cells on the other, and can not be distinguished as definite mesodermal cells until the blastopore is completely formed.

In other words, **the mesoderm first appears as a ring of cells just within the margin of the blastopore.** This mesodermal region is broadened considerably in the dorsal region.

As the blastopore closes, it carries mesodermal cells toward the midline (Fig. 324), where they form a broad median band extending forward from the dorsal lip of the blastopore. These cells then multiply, and as the dorsal lip extends downward, an **axial thickening** is formed. At this same time, the archenteron extends and carries yolk-cells outward toward the animal pole, so that the extent of the mesoderm is almost as great as that of the entoderm.

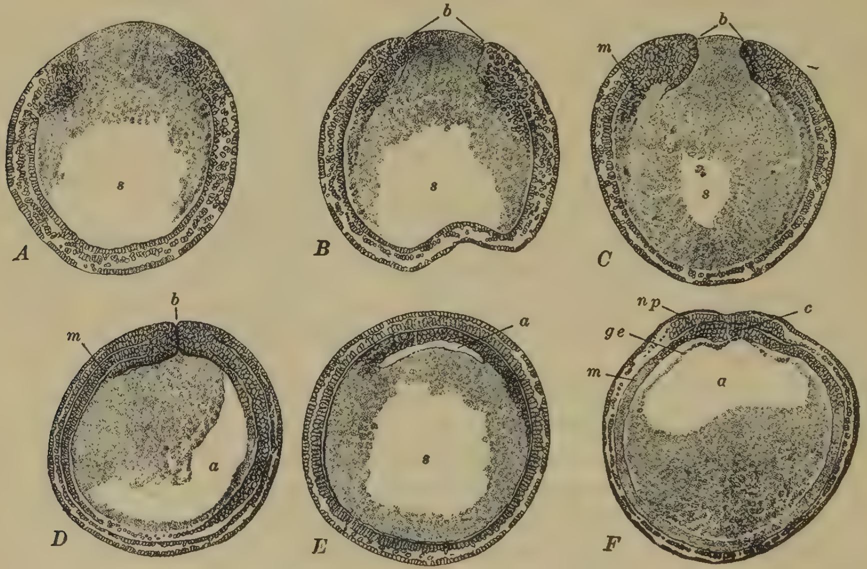


Fig. 324.

Frontal and transverse sections through gastrulas of the frog (*R. temporaria*) of various ages. *A.* Frontal section through gastrula of same age as Fig 323. *C. B.* Frontal section through gastrula of same age as Fig. 323, *D. C.* Frontal section through gastrula slightly older than Fig. 323, *F. D.* Frontal section through gastrula of same age as Fig. 32, *G. E.* Transverse section through gastrula slightly older than Fig 323, *D. F.* Transverse section through gastrula slightly older than Fig 323, *G. a,* Archenteron; *b,* blastopore; *c,* notochord; *ge,* gut endoderm; *m,* peristomial mesoderm; *np,* neural plate; *s,* segmentation cavity or blastocœle. (After Brachet.)

Then a rearrangement of cells takes place, so that an irregular delamination commences in the dorsal lateral regions on each side of the thickened axial mass, and extends from there anteriorly and laterally around the sides of the archenteron. Thus, a thick layer of mesoderm is formed between the entodermal lining of the archenteron and the outer ectoderm (Fig. 324, m).

At the lower pole, that is, toward the place where the yolk-plug is being drawn into the interior of the egg (Fig. 324, b), the lower surface of the yolk is also delaminated so that a circular margin of the mesoderm is formed there. It is from this layer of mesoderm that cells and groups of cells bud off and pass toward the lower pole—(it is to be remembered that these cells and groups of cells begin their growth **in the lower pole** region, but lie above the lower pole itself)—toward the ventral portion of the blastopore, so that a more or less completely continuous layer of mesoderm is formed between the ectoderm and entoderm.

In the dorsal region of the blastopore, and extending along the dorsal axial mass, delamination does not occur as rapidly as in the ventral region. The course of delamination is also modified, here. This modification is no doubt due to the fact that in this dorsal axial region the cells which are to become mesoderm are derived from the cells which invaginated from the outer layer, while in other regions this is not the case. Then, too, it is in this region that the notochord forms, which further complicates matters.

In fact, cross sections in the region of the blastopore do not show

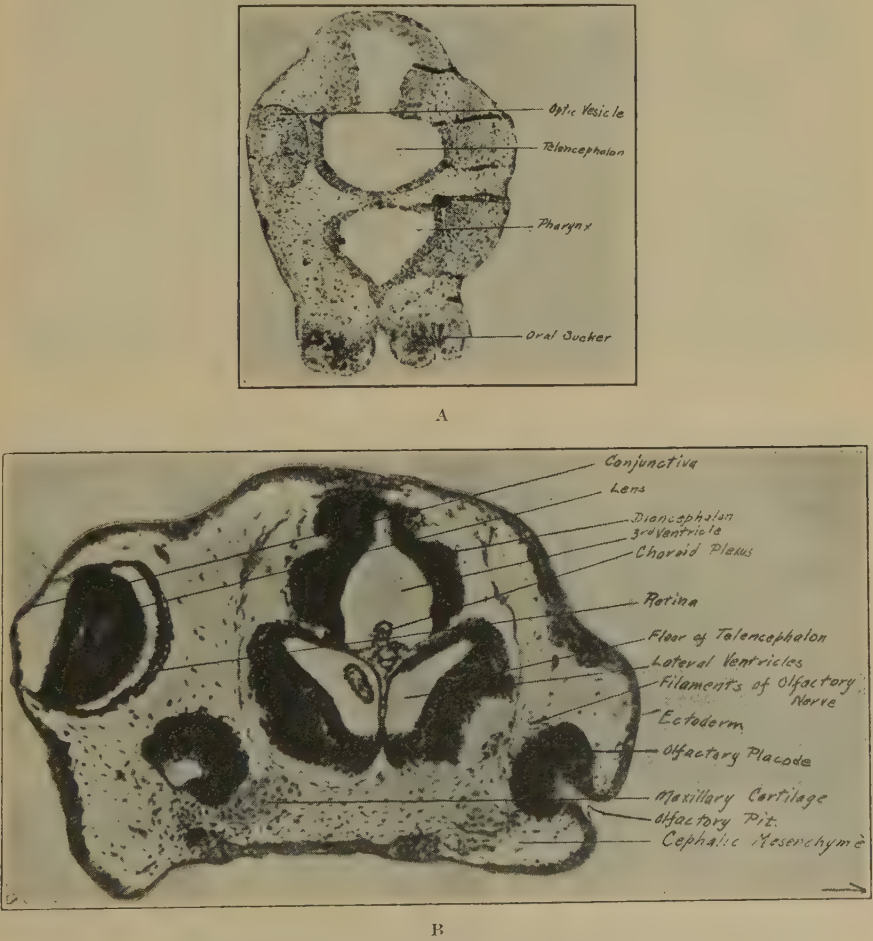
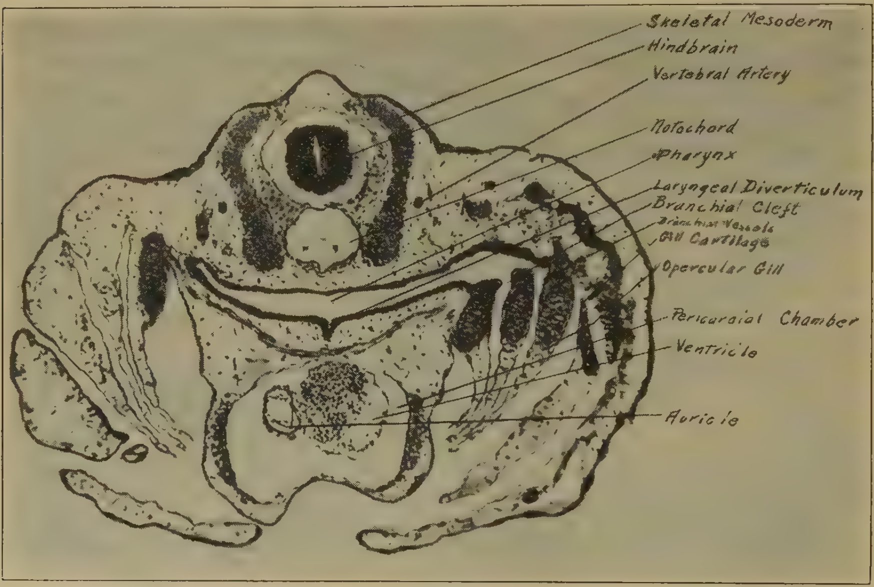


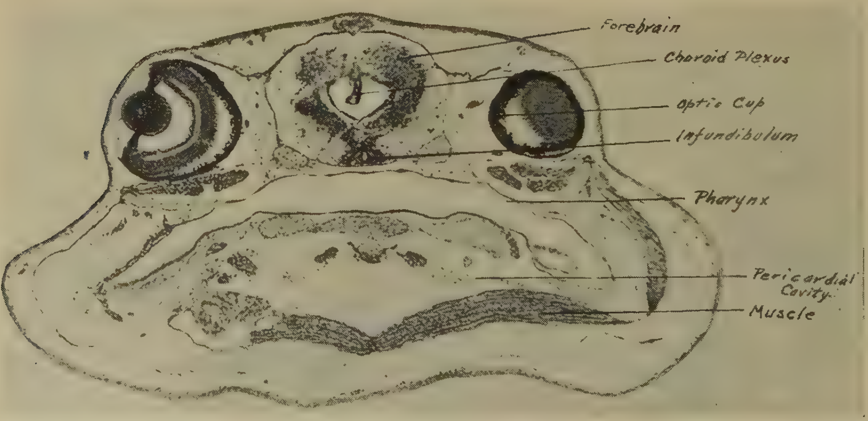
Fig. 325.

A, B, C, Transverse sections of *Amblystoma* tadpole. *A*, through suckers; *B*, through optic and olfactory region; *C*, through gill region.

lines of demarcation between the notochord, mesoderm, and the dorsal entoderm for some little time; but sections through the blastopore (while the yolk-plug is still protruding) show the rim of the blastopore to be composed of thick, undifferentiated cells which are a part of the contracted germ-ring. A little laterally, the ectoderm is separated by a narrow space or line which has formed during gastrulation, and the



C



D

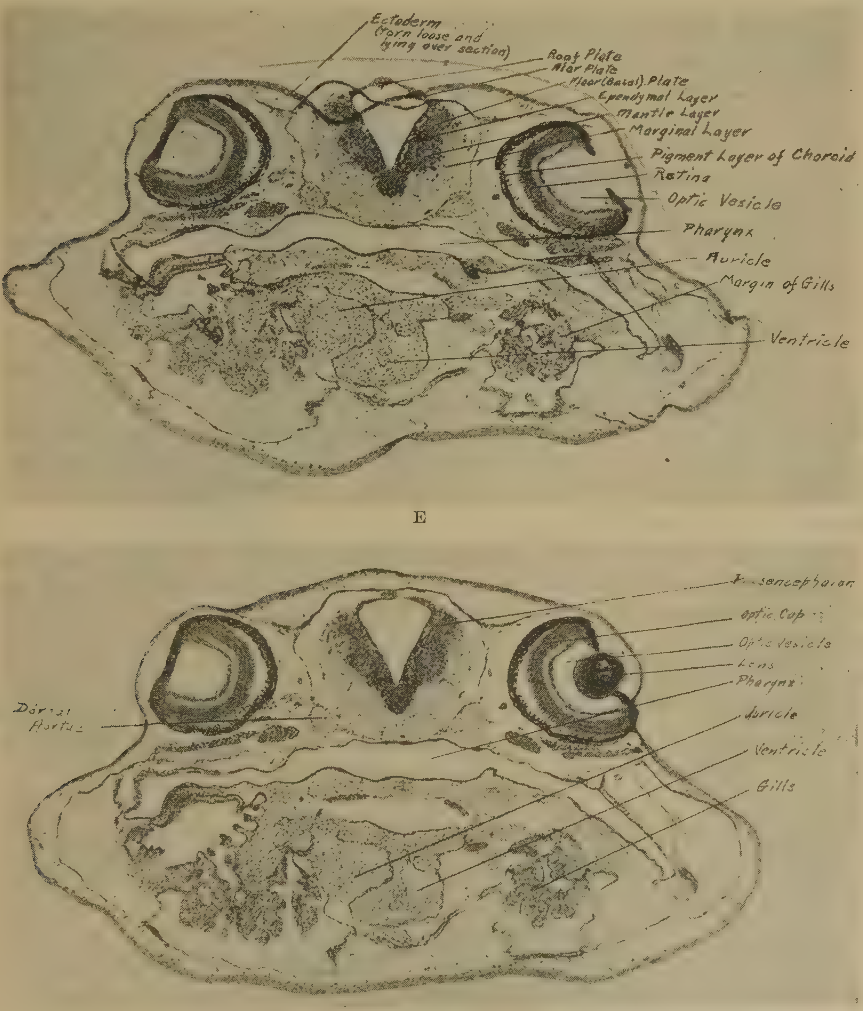
Fig. 325.

D, E, F, Photographs of transverse sections through 12 mm. frog tadpole. The sections are cut diagonally, the left eye (right side of figure) lying more cephalad; is the most anterior. *E* immediately posterior to *D*, but lens was lost sectioning; *F*, immediately posterior to middle cut.

thin entoderm is separated from the middle layer. This separation of layers is the **delamination process** we have been discussing.

As the **outer animal cells are pigmented,** we assume that whenever pigment is found in any of the inner cells, it is an indication that such pigmented cells are derived from the ectoderm.

As the yolk-plug is withdrawn, the blastopore becomes a mere slit, while the ectoderm and mesoderm separate considerably, and dip downward toward the entoderm in the dorsal midline, although never so far



E

F

Fig. 325.

as to reach the entoderm. This leaves a narrow, vertical ridge of cells at the midline.

A pair of slight depressions from the archenteron push upward and appear only as virtual grooves formed by pigmented cells. Forward from this, the lower margins of these grooves come to look like lips which approach the midline. The mesoderm in the meantime separates from the archenteron to a considerable extent (Fig. 324).

Still farther forward, the grooves disappear, while the spaces between mesoderm and entoderm, as well as between mesoderm and ectoderm, extend vertically and delimit the pair of mesoderm masses.

The cells thus left in the midline between the mesodermal sheets form a wedge-shaped elevation which is continuous with the entoderm. This is the **beginning of the notochord.** (Figs. 323, G, c, and 324, F, c,).

The notochord is now cut off from the entoderm by a narrow slit which leaves the archenteron with a dorsal roof, one cell in thickness. (Fig. 324.)

From this point posteriorly (toward the blastopore), the grooves of the archenteron are better marked.

THE MEDULLARY PLATE

At the same time that the notochord is developing, the medullary plate is also being formed (Figs. 324, np, and 326, everything above mes.), partly from the medial band of cells which extends from the region of the dorsal lip of the blastopore nearly to the animal pole, and partially from the axial thickening caused by the confluence of the lateral portions of the germ-ring.

The inner portion of the former region is called the **nervous layer** of ectoderm. It is this nervous layer which begins to thicken, and by the time the blastopore has begun to close, a thickened medullary plate has formed over the entire dorsal surface of the gastrula, essentially like that described in the chick.

At about the time the yolk-plug has disappeared, the lateral ridges have become elevated and form the **lateral neural ridges** (Fig. 327, n, f).

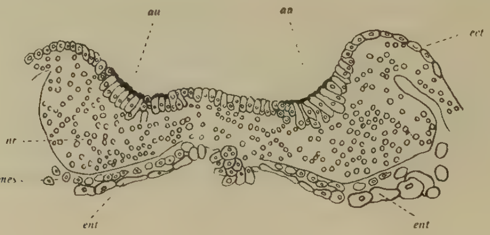


Fig. 326.

Transverse section through frog tadpole in the anterior region of the neural groove. *au*, eye-pits. (Note the pigment in the outer cells); *ect*, outer layer of ectoderm; *ent*, entoderm; *mes*, mesoderm; *nr*. anlage of the neural crest. (After Eyclesheymer.)

These extend from the blastopore to almost directly opposite on the dorso-lateral portion of the embryo. Here they turn sharply to pass toward the midline where they meet to form the **transverse neural fold.** It is this latter fold which marks the anterior limit of the medullary plate. The median groove becomes more pronounced and is then called the **neural groove.**

The important points to bear in mind here are:

First, that as in the chick and all chordate animals, so, too, in the frog, the closing of the blastopore by confluence (extending in an antero-posterior direction, on the dorsal aspect of the embryo) forms a definite axis, which means that by this confluence, the germ-ring becomes the axis. It is on each side of this axis that organs and important structures develop.

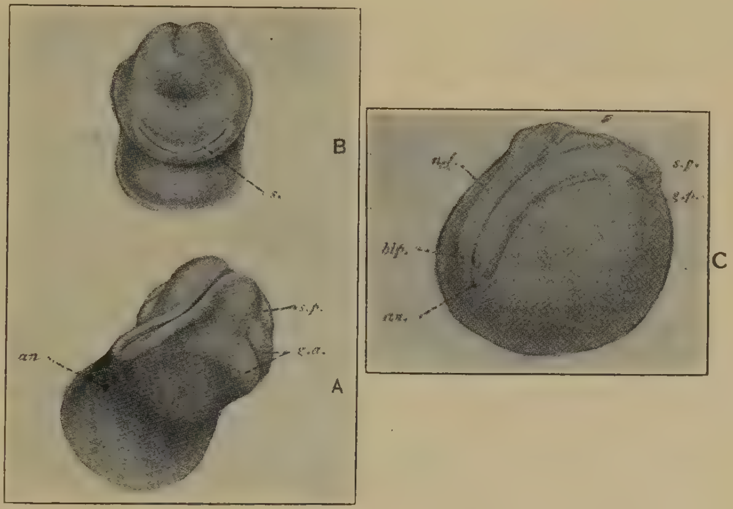


Fig. 327.

Frog embryos. *A*, from behind and above; *B*, from in front; *C*, slightly earlier than *A* and *B*. *an.*, proctodeum (the invagination from which anus will form); *blp.*, blastopore; *ga*, gill arches; *gp.*, gill plate; *nf.*, neural fold; *s*, sucker; *sp.*, sense plate. (After Borradaile.)

Second, that **gastrulation** involves only the forming of two layers (ectoderm and entoderm) from the single layered blastula.

Third, that **notogenesis** includes all the processes involved in the formation of the medullary plate, notochord, and mesoderm.

Gastrulation is accomplished in the frog chiefly by a delamination and rearrangement of the yolk cells and only to a slight extent by invagination. The process of invagination is chiefly concerned in forming the beginning of the notochord and the mesoderm in the dorsal and dorso-lateral regions. These latter structures are not formed entirely, however, by invagination, but also by material from the germ-ring which has been carried to the axial region. Invagination, in the frog, is therefore considered of minor importance.

Amphioxus is the only chordate which remains in a two-layered state for some time. All other chordates retain this condition for a short period, and this is so because the mesoderm begins its development almost at the moment of gastrulation.

In fact, in the frog, mesodermal cells are found almost immediately after the entoderm cells **begin** to form. They are found, first, all around the margin of the blastopore where they form an important part of the germ-ring. Mesoderm which forms in this way is called **blastoporal** or **peristomial.**

As confluence begins, the lateral portions of the germ-ring are brought closer to the mid-dorsal region where they become a part of the axis of the elongating embryo. That is, they form the mesodermal bands, already referred to, and it is these bands of the germ-ring which become **axial in position,** then to be known as **gastral mesoderm.** This gastral mesoderm is nothing more nor less than mesoderm derived in turn from the blastoporal mesoderm. It is no different from any other mesoderm derived from the same origin, although it lies, of course, in a different position from the remaining mesoderm. In **Amphioxus,** the above statement, however, is not true; for, in that animal, gastral mesoderm and blastoporal mesoderm have different origins. This difference in origins may be traced to the fact that in the frog the mesoderm differentiates **before** gastrulation and confluence, while in **Amphioxus,** the mesoderm does not differentiate until **after** these two processes have begun.

THE FORMATION OF THE EMBRYO

All that has been discussed so far has taken place within two days after fertilization. Now the embryo can be seen either lying in a straight line on the dorsal surface or slightly concave, while the ventral surface appears convex. The ectoderm still forms the entire covering epithelium, although some of these ectodermal cells have developed cilia which appear just before the fusion of the neural folds. These cilia beat in a posterior direction, thus giving the embryo a slow, rotary motion within the egg membranes.

The **transverse neural fold** marks the anterior limit of the nervous system, while the posterior limit is located just anterior to the dorsal lip of the blastopore.

As confluence continues, the nervous system comes to extend from almost pole to pole on the posterior surface of the gastrula, even before the blastopore has entirely contracted. The gastrula then rotates so that this posterior portion becomes dorsal, thus bringing the transverse neural fold to the anterior end of the nervous system, while the medullary plate occupies nearly the entire dorsal surface of the embryo.

The ridges which form on the neural plate and later fuse in a similar manner to that described in the chick. begin fusion in the region of the medulla (Fig. 327), and continue both anteriorly and posteriorly. The transverse fold extends backward so as to form the roof of the expanded brain end of the developing nervous system. It meets the lateral folds in the region lying between the fore and mid-brain, and as it is the last region of the neural tube to close, it is called the **neuropore.** The neuropore lies just posterior to where the **epiphysis** is to appear. It is quite transitory.

Neural crests are formed in a similar manner to the way they were formed in the chick embryo.

The blastopore has become a narrow slit, the lateral walls of which fuse, leaving two openings, an upper and a lower. The upper one is directly continuous with the archenteron, while the lower one is known as the **proctodaeum.** The proctodaeum is but a slight depression lined with ectoderm.

The posterior ends of the neural folds extend out from the middle regions where they fuse, to form the neural tube which then covers the upper blastoporal opening, thus forming a connection between arch-

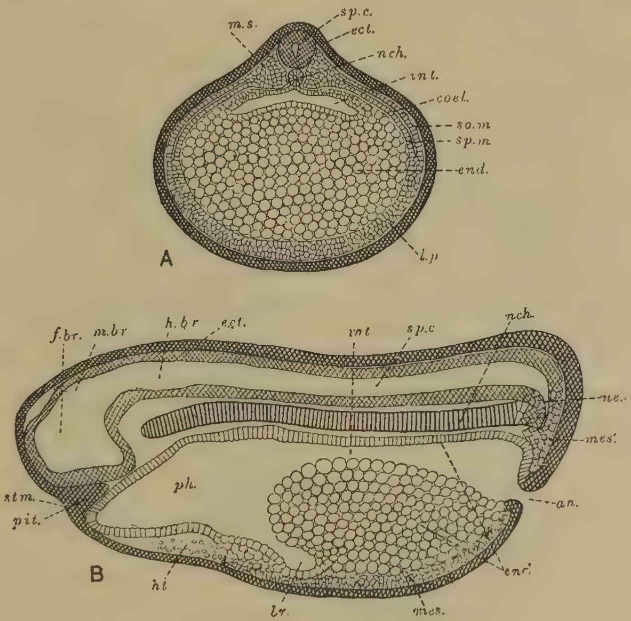


Fig. 328.

Sections of an embryo frog. *A*, transverse; *B*, longitudinal. *an.*, Anus., *cœl.*, cœlom; *ect.*, ectoderm or epiblast; *end.*, endoderm or hypoblast; *f.br.*, fore-brain; *h.br.*, hind-brain; *ht.*, rudiment of heart; *int.*, intestine; *l.p.*, lateral plate of mesoblast; *lr.*, rudiment of liver; *m.br.*, mid-brain; *m.s.*, mesoblastic somite; *mes.*, mesoblast; *mes'.*, mesoblast continuous with epiblast of neural canal and hypoblast of notochord; *ne.c.*, neurenteric canal; *nch.*, notochord; *ph.*, pharynx; pit., rudiment of pituitary body; *so.m.*, somatic mesoblast; *sp.c.*, spinal cord; *sp m.*, splanchnic mesoblast; *stm.*, stomodæum. (After Borradaile.)

enteron and neural tube. This opening is called the **neurenteric canal.** (Fig. 328.)

Just as with the chick, the confluence of the two lateral walls of the blastopore (which have been formed from the remains of the germ-ring) bring a median cell mass together in the axial region, in which ectoderm, entoderm, and mesoderm, are fused in a quite undifferentiated mass. This is the **primitive streak.** The groove which lies in the mid-line of the primitive streak is called the **primitive groove.**

It is from this primitive streak that ectodermal cells are budded forth into the neural folds and upon the surface of the body. It is from the primitive streak, also, that mesodermal cells are budded off into the lateral bands, and entodermal cells into the walls of the archenteron.

At this time the chief characteristic of the brain is the **single flexure** around the tip of the notochord (Fig. 329). The **hypophysis** (pituitary body) can be seen as a tongue of ectodermal cells just beneath the end of the fore-brain; it extends inward a short distance.

The rudiments of the eyes (Fig. 326, au) are indicated as small patches of the deeply pigmented ectodermal epithelium in an antero-lateral region of the medullary plate.

The rudiments of the ears (Fig. 282, C) are seen as thickened patches of the inner or nervous layer of ectoderm opposite the region of the hind-brain. They are difficult to see externally as yet.

The rudiments of the olfactory organs are formed as thickened patches of ectoderm below and in front of the optic rudiments. The tiny depressions on the surface which are to form the future olfactory pits may sometimes be seen at this period.

The notochord is completely delaminated except in the region of the primitive streak, by the time the neural tube has closed.

By the time the neural tube is completed, the archenteron is called a **mesenteron,** the anterior enlarged end forming the **fore-gut,** the walls of which are but one cell in thickness (Fig. 329). This is also called the **pharynx** in the embryo. The stomach and oesophagus are later to be developed from this region.

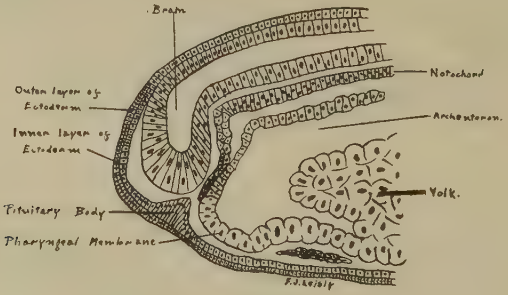


Fig. 329.

Sagittal section of Anterior end of a frog tadpole 3.6mm. long. (Redrawn from Corning.)

Just in front of the neurenteric canal there is an enlargement also, which forms the **hind-gut** or **rectal portion** of the intestine.

The **mid-gut** is, as in the chick embryo, that small portion in direct connection with the yolk.

It will be remembered that the true mouth forms in chordates as a secondary inpocketing of ectoderm. In the frog, the outpocketing from the fore-gut which is to meet the ectodermal inpocketing is seen just below the fore-brain (Fig. 329, pharyngeal membrane). This is the region where the mouth will form later.

The liver will be seen as a ventral outgrowth beneath the anterior end of the yolk mass (Fig. 328).

In sections, the rudiments of the first two or three visceral pouches can be seen as vertical outgrowths from the sides of the pharyngeal walls (Figs. 295 and 330). The pouches extend to the ectoderm with

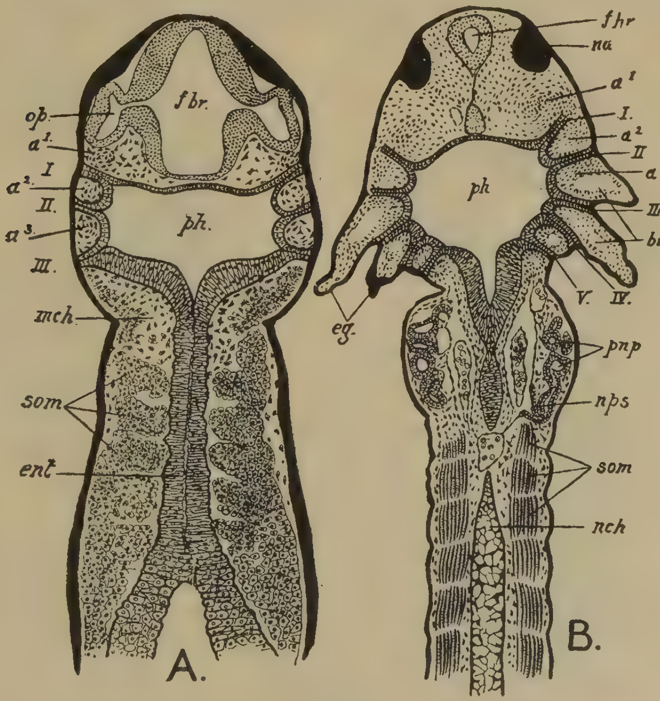


Fig. 330.

A. Horizontal section through an embryo frog some time before hatching, showing the optic vesicles springing from the sides of the fore-brain, the three anterior pairs of gill-slits, and five pairs of mesoblastic somites. *B.* A similar section through a tadpole shortly after hatching. The head is cut in a lower plane than in *A*, so only a small part of the anterior end of the brain appears in the section. a^1, the mandibular arch; a^2, the hyoid arch; a^3, the first branchial arch; *bv*, blood-vessel in first and second branchial arch; *eg*, external gills; *ent*, enteron; *fbr*, fore-brain; *mch*, branching mesenchyme cells; *na*, nasal pits; *nch*, notochord; *nps*, peritoneal funnel; *op*, optic vesicle; *ph*, pharynx; *pnp*, pronephros; *som*, mesoblastic somites which in *B* are converted into muscle. *I*, mandibulo-hyoid slit; *II*, hyo-branchial slit; *III-V*, branchial slits. (After Bourne.)

which they fuse. It is this fusion which causes the depressions in the ectoderm just back of the head on the external surface.

THE SOMITES

Just as with the chick, somites are formed by transverse division along the dorsal portion of the embryo, except in the primitive streak

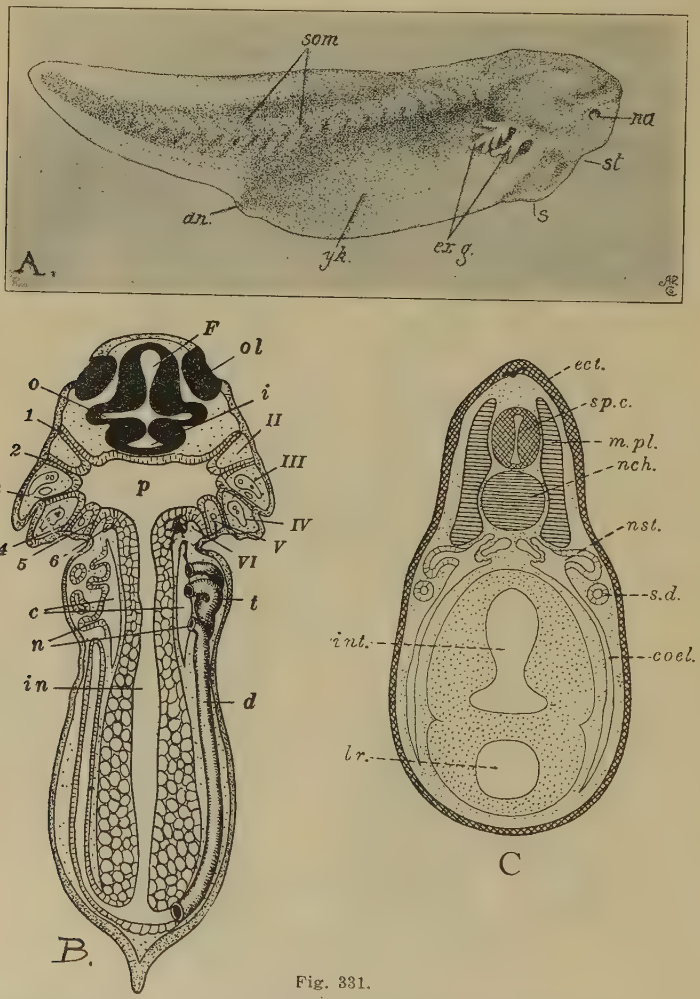


Fig. 331.

A. Tadpole of the frog at the time of hatching. *an*, anus; *ex.g*, external gills *na*, nasal pit; *s*, sucker; *som*, somites; *st*, stomodæum; *yk*, yolk-sac.

B. Diagram of a frontal section of a frog larva at the time of hatching. (modified.) *c*, Cœlom; *d*, pronephric duct; *F*, fore-brain; *i*, infundibulum; *in*, intestine; *n*, nephrostome; *o*, base of optic stalk; *ol*, olfactory pit (placode); *p*, pharynx; *t*, pronephric tubules; *II*, hyoid arch; *III-VI*, first to fourth branchial arches; *1*, hyomandibular pouch; 2-6, first to fifth branchial pouches.

C. A diagram of a transverse section of the frog embryo at the hatching stage. *cœl.*, Cœlom; *ect.*, ectoderm; *int.*, intestine; *lr.*, liver; *m.pl.*, muscle plate; *nch.*, notochord; *nst.*, nephrostome; *s.d.*, segmental duct; *sp.c.*, spinal cord. The glomeruli are seen opposite the nephrostomes. (*A* and *C*, after Borradaile; *B*, after Marshall.)

region and in the head region. A complete sheet of mesoderm now separates ectoderm and entoderm in the embryo from the head region to the primitive streak region, and this sheet separates into two layers, an outer or **somatopleure,** and an inner known as the **splanchnopleure.** (Fig. 268.)

The thickened region where the somites form on the dorsal surface of the embryo along the notochord is called the **segmental plate** or **myotomal region,** while the portion extending laterally (which is much thinner) forms the **lateral plates.**

The **coelom** develops between somatopleure and splanchnopleure.

As the frog's egg has the yolk-mass **packed within** the embryo, this mass pushes the germ layers close together, so that they are by no means as clearly set apart as in the chick embryo.

Between the second, third, and fourth somites and the lateral plates, small masses of cells remain closely related to the somatopleure of the lateral plate. It is these cell masses which are to develop into the **pronephric tubules.** All of these structures must be compared with similar developmental structures in the chick embryo, at this point.

The coelom proper can be seen as a definite space only below the pharynx in front of the liver (Fig. 331). The heart will develop in the region where the loosely scattered cells are seen, ventral to the pharynx.

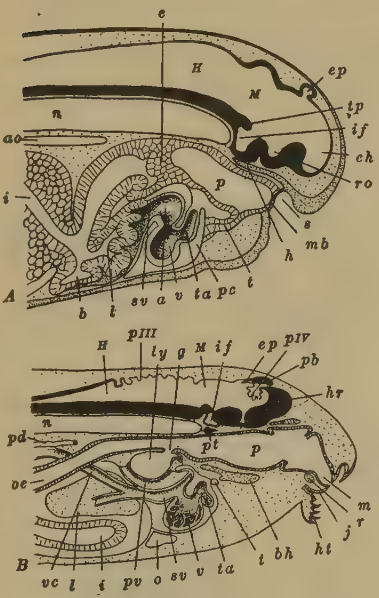


Fig. 332.

Diagrams of median sagittal sections of the anterior ends of frog larvæ. *A.* Of a larva just before the opening of the mouth. *B.* Of a 12 mm. larva (at the appearance of the hind-limb buds). *a,* Auricle; *ao,* dorsal aorta; *b,* gall bladder; *bh,* basihyal cartilage; *ch,* cavity of cerebral hemisphere (lateral ventricle); *e,* epithelial plug closing the œsophagus; *ep,* epiphysis; *g,* glottis; *h,* hypophysis; *H,* hind-brain; *hr,* cerebral hemisphere; *ht,* horny "teeth"; *hv,* hepatic vein; *i,* intestine; *if,* infundibulum; *j,* lower jaw; *l,* liver; *ly,* laryngeal chamber; *m,* mouth; *M,* mid-brain; *mb,* oral membrane (oral septum); *n,* notochord; *o,* median portion of opercular cavity; *œ,* œsophagus; *p,* pharynx; *pb,* pineal body; *pc,* pericardial cavity; *pd,* pronephric (mesonephric) duct; *pt,* pituitary body; *pv,* pulmonary vein; *pIII,* choroid plexus of third ventricle; *pIV,* choroid plexus of fourth ventricle; *r,* rostral cartilage; *ro,* optic recess; *s,* stomodæum; *sv,* sinus venosus; *t,* thyroid body; *ta,* truncus arteriosus; *tp,* tuberculum posterius; *v,* ventricle; *vc,* inferior (posterior) vena cava. (After Marshall.)

THE LATER DEVELOPMENT OF THE TADPOLE

There are details in which the various species of frogs vary, but all pass through the following general method of development.

It is both interesting and profitable to call attention at this point to the fact that, while the frog was one of the earliest forms of animal life studied in the laboratory, and while many hundreds of volumes and articles have been written on it from many angles, there are nevertheless hundreds of interesting points in that animal's development which are unknown. In fact, one writer says that the gaps that confront one in the study of the frog assume "remarkable proportions" when one thinks of how much work has really been done on this much-studied animal.

Then, too, as there is no accurate method of obtaining the age of a frog, owing to the remarkable influence temperature and food play in its development, it is often difficult to make clear much that should be made clear to the student.

Roughly speaking, at the time of hatching, namely, about one or two weeks after fertilization, the larvae of most species are about six or seven millimeters in length. The tadpole is usually about nine or ten millimeters in length at the time of the opening of the mouth, and eleven or twelve millimeters when the limb-buds appear.

THE NERVOUS SYSTEM

There are no neuromeres in the brain region of the frog, though otherwise the same brain divisions take place that we have discussed in the chick.

The **tuberculum posterius** (Fig. 332, tp) is a thickening opposite the tip of the notochord in the floor of the brain, while a dorsal thickening appears in the roof of the brain obliquely upward and forward from this. A plane passing from the tuberculum posterius in front of the dorsal thickening separates the fore-brain from the mid-brain, while a plane passing from the same tuberculum behind the dorsal thickening separates the mid-brain from the hind-brain.

The beginning of the brain divisions is quite similar to the three primary regions mentioned in the chick embryo, and a review of the matter there given will make the divisions and cavities in the frog understandable.

It will be remembered that the olfactory lobes and the cerebral hemispheres form the **telencephalon,** and that the telencephalon and the "tween-brain" **(diencephalon)** together form the fore-brain, while the optic lobes and optic chiasma form the main portions of the **mesencephalon.** The **cerebellum** takes up most of the **metencephalon,** while the **medulla oblongata** forms the **myelencephalon.**

THE FORE-BRAIN

Opposite the neuropore (Fig. 328) the cells of the ectodermal cone scatter, due to the pushing out of the head tissues in advance of the brain. Soon all trace of the neuropore disappears except for a slight indentation known as the **olfactory recess,** and this also disappears a short time later.

The **lamina terminalis** (Fig. 282, C) is a thickening just below the level of the olfactory recess in the anterior wall of the fore-brain. It extends ventrally to where the optic stalks protrude. From the drawing (Fig. 333) it will be noticed that a thickening occurs in the region of the attachment of the optic stalks to form the **torus transversus** (Fig. 333, tr) and the beginnings of the **optic chiasma** (Fig. 333, cw) and **thalami.** The torsus transversus becomes the seat of the **anterior commissure** (Fig. 333, cpa) as well as other **commissures** of the brain.

The narrow depression between the thickenings just mentioned forms the **recessus opticus** (Fig. 333, ro), which is the passage to the cavities in the optic stalks.

The **infundibulum** (Fig. 333, J) is an outgrowth of the posterior portion of the fore-brain where it extends backward under the tip of the notochord.

The **epiphysis** or **pineal body** (Fig. 333, e) is an evagination from the dorsal wall of the fore-brain at its posterior limit where the wall has become quite thin.

The **choroid plexus** (Fig. 333, pch) is the non-nervous portion of the roof of the fore-brain which has become thinned out considerably, and in which the blood vessels lie. This whole region is pushed into the third ventricle.

The **habenular ganglia** and the **habenular commissure** (Fig. 333, ch) develop between the choroid plexus and the epiphysis.

The **paraphysis** (a dorsal growth) develops in front of the habenular ganglia and commmissure considerably later.

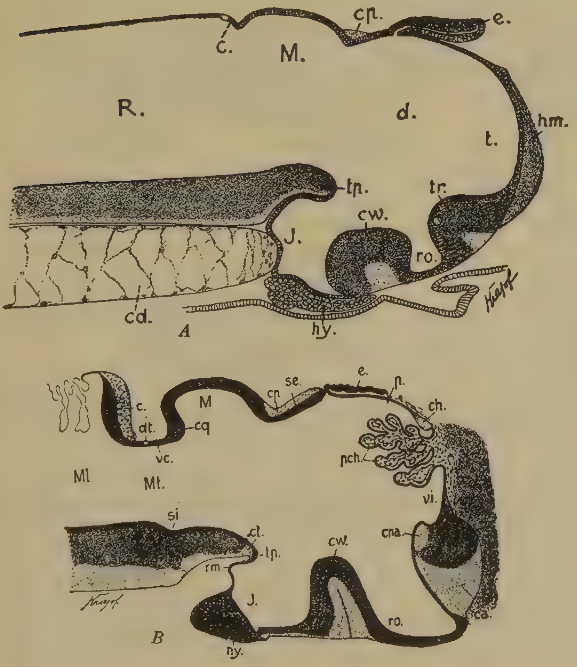


Fig. 333.

Median sagittal sections through the brain of the frog. *A.* Of a larva of *R. fusca* of 7 mm. in which the mouth was open. *B. R. esculenta* at the end of metamorphosis. *c*, Cerebellum; *ca*, anterior commissure; *cd*, notochord; *ch*, habenular commissure; *cp*, posterior commissure; *cpa*, anterior pallial commissure; *cq*, posterior corpus quadrigeminum; *ct*, tubercular commissure; *cw*, optic chiasma; *d*, diencephalon; *dt*, tract of IV cranial nerve; *e*, epiphysis; *hm*, cerebral hemisphere; *hy*, hypophysis; *J*, infundibulum; *M*, mesencephalon; *Ml*, myelencephalon; *Mt*, metencephalon; *p*, antero-dorsal extension of diencephalon; *pch*, choroid plexus of third ventricle; *R*, rhombencephalon; *rm*, recessus mammillaris; *ro*, optic recess; *se*, roof of diencephalon; *t*, telencephalon; *tp*, tuberculum posterius; *tr*, torus transversus (telencephali); *vc*, valvula cerebelli; *vi*, ventriculus impar (telencephali) (third ventricle). (From Von Kupffer, Hertwig's Handbuch, *etc.*)

The cerebral hemispheres appear when the tadpole is about seven millimeters in length, that is, when it is ready to hatch.

The ventricles are similar to those in the chick.

As all these thickenings and outgrowths appear, the brain itself seems to straighten the original flexure, but this is only **apparent,** as the flexure remains, and the infundibulum still extends below and in front of the tip of the notochord.

The **hypophysis** (Fig. 333, hy) grows as an inward extension of the surface ectoderm to meet with the infundibulum.

THE MID-BRAIN

There is not much change in this region of the brain except that the ventro-lateral walls thicken, and these thickened portions are known as the **crura cerebri.** They connect with the wall of the fore-brain. The dorso-lateral walls of the mid-brain form the large, rounded **optic lobes.**

The **posterior commissure** (Fig. 333, cp) forms the anterior limit of the mid-brain.

The **aqueduct of Sylvius** (Fig. 303) is the cavity in the mid-brain connecting the third ventricle with the cavity in the rhombencephalon.

THE HIND-BRAIN

There is little, if any, line of demarcation in the frog which divides the hind-brain into metencephalon and myelencephalon.

The **cerebellum** (Fig. 333, c) is in the region which is commonly designated as the metencephalon. This organ is quite small in the frog, and appears late in larval life on the dorsal side of the hind-brain.

The non-nervous thinned-out roof of the fourth ventricle (which covers the dorsal part of the region of the medulla oblongata or myelencephalon), (Fig. 333, Ml), forms the **choroid plexus of the fourth ventricle.**

The floor of the ventro-lateral walls of the hind-brain becomes thickened and forms the main nervous pathways to and from the nuclei of origin of most of the cranial nerves.

The brain gradually tapers into the spinal cord proper at the medulla oblongata.

The **central canal** is the central opening running throughout the length of the spinal cord. It is continuous with the cavities of the brain. This central canal is lined with non-nervous cells known as **ependymal cells.** The true nerve-cells which go to make up the main portions of the wall of the spinal cord are called **germinal cells.** These latter are in turn divided into supporting cells or **glia cells,** and the true functional nerve cells or **neuroblasts.**

There is no dorsal fissure in the frog's spinal cord as there is in higher forms, though there is a **ventral fissure.**

The **gray matter** of the cord is formed by the neuroblasts.

THE PERIPHERAL NERVOUS SYSTEM

The peripheral nervous system has been discussed in some detail in the chick, and will be taken up in comparative anatomy later.

In the tadpole there are some forty pairs of spinal nerves but only ten pairs in the adult. They arise by a **dorsal and ventral root**, which unite to form the **trunk of the spinal nerve**, after which this trunk divides into a **dorsal and a ventral ramus**, while a **ramus communicans** connects the trunk with the sympathetic system.

There are also ten **cranial** nerves instead of twelve as in the higher forms.

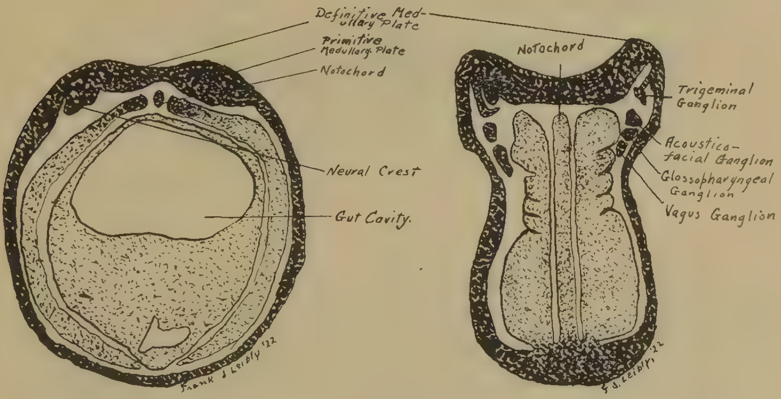


Fig. 334.

Transverse and frontal sections of frog embryo to show position and division of neural crest in head region.

The V, VII, IX, and X are called **branchiomeric nerves** on account of their close relationship to the branchial clefts.

The cranial nerves take their substance from three embryological elements, namely: (1) the cell masses derived from the neural crests as described in the study of the chick, (2) cells from ectodermal patches on the surface of the head, and (3) from the cell processes which extend outward from the neuroblasts in the ventro-lateral walls of the spinal chord.

They differ, therefore, from the spinal nerves, for in these (2) is lacking.

The V, VII, IX and X cranial nerves arise by a single root (though this may be mixed, i. e., it may be both sensory and motor in function) passing into a large ganglion, beyond which a large horizontal branch is given off which in turn branches into **two rami** which pass anteriorly and posteriorly to the gill cleft with which the particular nerve is associated.

As in the chick, so in the frog, the cranial nerves develop from the **neural crests** left on each side of the central canal after the neural folds fuse, and the indented ectoderm again returns to its normal condition.

The neural crests are thus left between the central canal and the outer ectoderm.

The neural crests are quite large in the head region, becoming smaller toward the posterior region of the embryo. Each crest becomes divided into three masses as the neural plate begins to close. (Fig. 334.)

The more anterior of these divisions which lies in the region of the mid-brain is the beginning of the V nerve, and is to form the **trigeminal ganglion.** The middle section is the beginning of the VIII and VII nerves, known also as the **acustico- facialis** ganglion, while the posterior division forms the beginning of the IX and X nerves, or the **glosso-pharyngeal** and **vagus ganglia.** The three divisions do not separate entirely from the medullary plate, but remain connected by a very slender chain of cells to the medullar region of the brain.

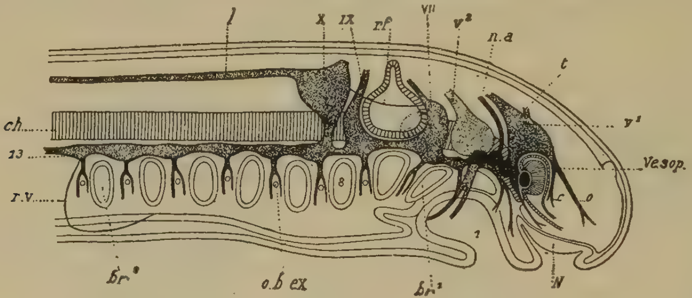


Fig. 335.

The Nerve Placodes in the head of an *Ammocoetes* 4 mm. long. V^1, first ganglion of the *V* cranial nerve; V^2, second ganglion of the same nerve; *VII*, ganglion of the *VII* cranial nerve; *IX*, ganglion of the *IX* nerve; *X*, ganglion of the *X* (Vagus) nerve. 1, 8, 13, first, eighth and thirteenth ganglia in the epibranchial series. br^1, br^8, first and eighth branchial pouches; *c*, ciliary nerve; *ch*, notochord; *l*, lateral ramus of the *X* cranial nerve; *N*, anlage of hypophysis; *n.a.*, *VI* cranial nerve (abducens); *o.*, ophthalmic nerve; *r.f.*, recurrent branch of *VII* cranial nerve (facial); *r.v.*, recurrent branch of *X* (vagus) nerve; *t.*, *IV* cranial (trochlear) nerve; *ves.op.*, optic vesicle. (From Vialleton after von Kupffer.)

When the tadpole has developed three or four somites, the inner or nervous layer of the ectoderm opposite the crest ganglia proliferates to form a patch, sometimes three or four cells in thickness. Such patches are known as **placodes** (Figs. 268, 335), and are thought to be **vestigial sense organs.**

In the placode there is found a **superficial sensory element** which may disappear, and a **deep ganglionic element** usually retained. It is the ganglionic portion which fuses with the nearest crest-ganglion, thus forming the principal sensory portions of the nerve.

THE TRIGEMINAL OR V NERVE

This is the principal nerve of the mouth and mandibular arch. The trigeminal portion of the neural crest is large and extends from the eye to the hyomandibular cleft (Fig. 335). The ectodermal and mesodermal cell-groups fuse as the crest ganglion grows downward. In the ventral region it meets the mesoderm of the mandibular arch.

It is important that the student note how the **mesenchyme** of the mandibular arch is formed by the process of growth just described. The mesodermal and ectodermal cells have so intermingled at the point of fusion that the separate cells of ectoderm and mesoderm are now indistinguishable. (Fig. 334.)

The dorsal and superficial cells of the crest ganglion retain their nervous character and come into close relation to the large placode close to them, but the superficial portion of the placode, which is **sensory**, now disappears. The deep or ganglionic portion not only enlarges, but divides into two parts. The anterior portion becomes the **ophthalmic** ganglion of the **ophthalmic branch** of the V nerve. The fibers of this branch grow cephalad through the dorsal head region, and also grow medially and connect with the medulla oblongata.

The posterior portion of the placode ganglion fuses with the crest ganglion to form the **Gasserian ganglion** or **trigeminal ganglion.**

It is from the cells of the trigeminal ganglion that fibers arise which run to the medulla on the dorsal side, and these fibers form the sensory root of the V nerve.

Then, too, there are fibers which grow out from the ganglion to pass to the surface of the head to form the **cutaneous branch** of the V nerve, while the fibers which pass in front of and behind the mouth are called the **mandibular** and **maxillary branches** respectively.

All of these branches as well as those from most of the branchiomeric nerves can be seen before the opening of the mouth.

THE FACIAL AND AUDITORY, OR THE VII AND VIII NERVES

Both of these nerves are derived from the acustico-facialis crest ganglion and the placode associated with it. The VII nerve is connected with the hyomandibular cleft, while the VIII nerve is a purely sensory (auditory) nerve, and so not one of the branchiomeric series.

The greater portion of the crest ganglion, as with the V nerve, contributes to the mesenchyme of the hyoid arch, although the nervous portion of the crest ganglion is more extensive than that of the V nerve, which is due to the fact that a greater portion of the original ganglion retains its nervous function.

The superficial or nervous character of the placode does not disappear in this case, but keeps on becoming larger, after which it sinks below the surface of the head and invaginates to form the **auditory sac.** (Fig. 334.)

The deep placode ganglion cells which are in connection with this sensory epithelium remain in contact with the sac to form the **root** of the VIII nerve.

The remaining portion of the placode ganglion joins with the nervous portion of the crest ganglion to form the ganglion of the VII nerve. It is from this ganglion that fibers pass to the medulla and to the hyoid arch and associated regions, to form the hyomandibular and palatine nerves.

THE GLOSSOPHARYNGEAL AND VAGUS (PNEUMOGASTRIC) OR IX AND X NERVES

The remaining visceral clefts, that is, the first to fourth clefts, or third to sixth visceral arches, are associated with the IX and X nerves.

The IX nerve is limited to the first gill cleft alone, but the X nerve is associated and distributed to the others. It is to be considered a compound nerve, as it is made up of several branchiomeric nerves.

The large posterior part of the neural crest in the head region is the portion associated with the IX and X nerves.

Its growth is much like that of the V nerve, though it does not assist in forming so much mesenchyme.

The superficial sensory portion of the placode of the IX nerve disappears, and its ganglionic portion is only slightly related to the crest ganglion.

Posterior to this, the larger placode of the X nerve appears simultaneously, and passes through similar stages, but in this case there is a more extensive fusion between it and the nervous portion of the crest ganglion.

The fibers from the IX and X ganglion pass out together **to** the medulla as a **single root.** The anterior cardinal vein partially separates the IX from the X ganglion.

The fibers which pass out from the IX nerve portion of the ganglion are practically all placodal in origin, and pass to the first branchial cleft, while the fibers coming from the mixed ganglion of the X nerve are connected with all the remaining clefts.

It is well to pay considerable attention to the X nerve, as it is one of the most important nerves in the body, being connected with many important structures.

It is from the X ganglion that other processes than those just mentioned, also grow. A considerable tongue of cells grows out posteriorly to form the sense organs of the **lateral line,** shortly to be discussed, while the fibers which are to become the **lateral line nerves** accompany this tongue (Fig. 340). These latter fibers are present only during the tadpole stage.

Then there are branches which pass to the thoracic and abdominal organs to form the visceral branch of the X nerve.

As sensory nerves pass **to** a general center, and motor nerves pass **from** a center to some outlying region, it is well to appreciate how some of the nerves mentioned above come to be **mixed,** that is, having both sensory and motor fibers running along side by side.

The motor fibers of the branchiomeric series do not arise by separate roots (Fig. 336) as do the sensory, but from neuroblasts in the walls of the medulla oblongata which send out processes called **axons**, which leave the medulla in close association with the sensory roots already described. These are then distributed with the branches passing posterior to the gill clefts.

The III cranial nerve is the first of the remaining III, IV, and VI to appear, although all three of these form later than the ones discussed above, that is, they form when the tadpole is five to six millimeters in length.

The III is called the **oculo-motor**, the IV the **trochlear**, and the VI the **abducens**. All are motor nerves, which innervate the muscles of the eye-ball.

The I cranial nerve is the purely sensory **olfactory** nerve and the II is likewise a purely sensory nerve, namely, the **optic**.

THE SPINAL NERVES

These nerves, unlike the cranial nerves, are related to the somites, and not to the visceral clefts, and there are no placodes connected with them.

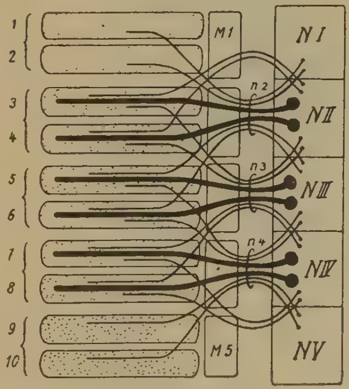


Fig. 336.

Schematic arrangement to show the composition of the central nerve roots in shark fins. The motor fibers run to the muscles, and each motor spinal root is made up of the fibers of three spinal segments. NI, II, III, IV, V, Neuromeres; N2, N3, N4, corresponding motor roots; M1-M5, Myomeres; 1-10 Divisions of Myomeres. (From Rabl.)

The two most anterior myotomes do not have spinal nerves connected with them, and the myotomes soon disappear, but the segments formed in the neural crests, posterior to the head region (with the exception of the two just mentioned), have cell processes grow out **into the cord** to form the **dorsal root of the spinal nerves**, while others grow **away from the cord** to form the **peripheral strands** which are distributed to the skin and other sensory surfaces.

The ventral root of the spinal nerve is formed by outgrowths or axons from the neuroblasts on the ventral side of the cord, and appear when the tadpole is about four millimeters in length. These then meet the dorsal root a little distance beyond the ganglion, and pass partly to the mesodermal myotomes and partly to the sympathetic system.

THE SYMPATHETIC SYSTEM (Fig. 337)

When the tadpole is about six millimeters in length, one may see a slight collection of cells on the spinal nerves at about the level of the dorsal aorta. From our study of the sympathetic system in higher animals, we assume that these cell-groups are composed of elements from the spinal ganglia, and from some of the posterior cranial ganglia.

The cells themselves migrate ventro-medially to form a pair of longitudinal **sympathetic cords,** along each side of the dorsal aorta. It is from these cords, then, that processes grow back to the spinal ganglia to form **the rami communicantes,** as well as outwardly to the various organs and surfaces.

Other fibers from other spinal ganglia grow out and follow the paths thus laid down for them, while cells from the sympathetic cord probably also migrate to form the large **sympathetic ganglia** found in close connection with the large blood vessels, and the thoracic and abdominal viscera. The fact of the matter is that the sympathetic nervous system of the frog has not been worked out with any degree of thoroughness, and we can only suppose many things from our knowledge of other forms where more is known of this system.

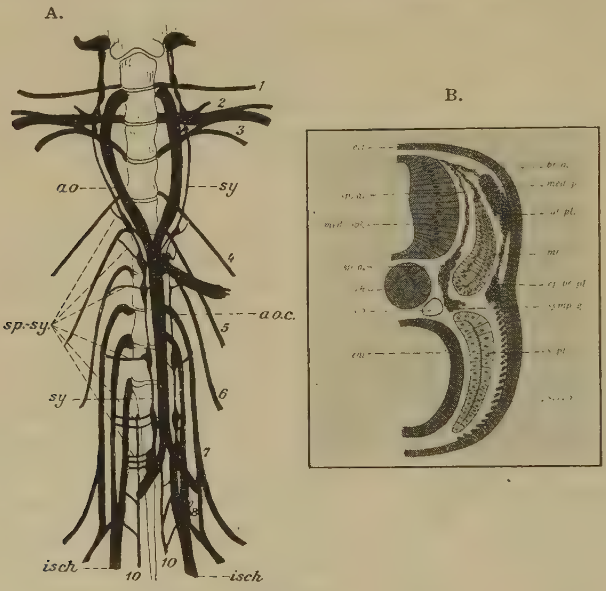


Fig. 337.

A. Sympathetic nervous system of the Frog. *ao*, aortic arch; *ao.c.*, common aorta; *isch*, ischial nerve; *sp.sy.*, communicating branches between the spinal and sympathetic nerves; *sy*, the two branches of the sympathetic system; 1-10, spinal nerves. (After Meissner.)

B. One-half of a transverse section of Ammocoetes, in the head-region. Schematic. *ao*, aorta; *br.a.*, branchial branch of nerves; *ch*, notochord; *ep.br.pl.*, ganglion anlage which develops where the epibranchial placode forms; *ect*, ectoderm; *ent*, entoderm; *lat.pl.*, lateral placode; *med.pl.*, medial placode; *med.obl.*, medulla oblongata (hind-brain); *mt*, myotome; *s.c.a.*, subcutaneous branch of the epibranchial nerve placode; *sp.a.*, spinal branch running inward; *s.pl.*, lateral plate of mesoderm; *symp.g.*, sympathetic ganglion. (After von Kupffer.)

The ganglion of the III cranial nerve is sympathetic in character, as other cranial nerves may be, but this must be left for future workers to demonstrate.

THE EYE (Fig. 338)

The general method of the eye formation is quite similar to that already described in the chick.

As the outer free rim of the optic cup draws together, it leaves a small opening which is the rudiment of the pupil. At this time we can distinguish the inner and outer layer to the cup, and a central cavity. These are the beginnings of the true **retinal layer**, the **pigment layer**, and the **posterior chamber** of the eye respectively.

There is a choroid fissure formed, just as in the chick.

The lens forms as a thickening of the ectoderm opposite the pupil, but this thickening involves only the nervous layer of the ectoderm. It develops quite similarly to the ectodermal placodes in the formation of the cranial nerves. In fact, the lens placode lies immediately anterior to the placode of the V cranial nerve. About the time of hatching, the lens has formed a prominent rounded thickening entirely cut off from the ectoderm.

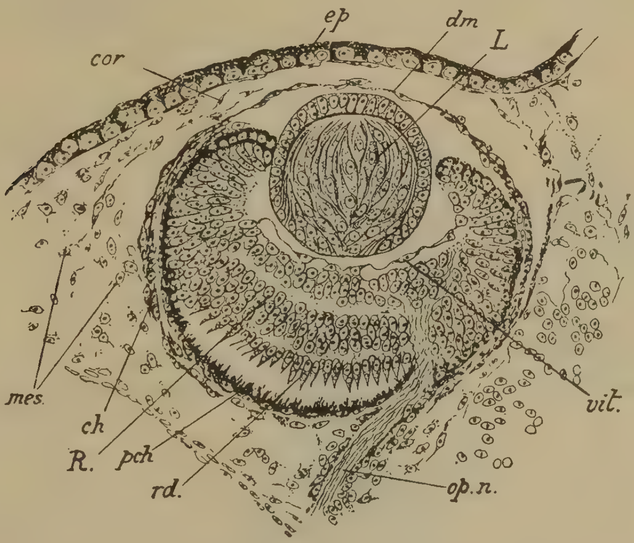


Fig. 338.

Section through the eye of a tadpole at the time when the operculum is forming, much magnified. *ch*, choroid; *cor*, mesoblast cells which will give rise to the cornea; *dm*, Descemet's membrane; *ep*, pigmented external epithelium; *L*, lens; *mes*, branched mesoblast cells; *op.n.*, optic nerve; *pch*, pigmented epithelium of the choroid; *R*, retina; *rd*, rods and cones pulled away from the pigmented epithelium of the choroid by contraction of the preparation; *vit*, cells of the vitreous humour. (After Bourne.)

This spheroidal mass hollows out, although it again becomes solid by the cells on its inner side elongating, while the outer side remains as a thin epithelial layer covering the distal surface of the lens. Then, as the pupil narrows, the lens comes to lie just within the opening of the cup.

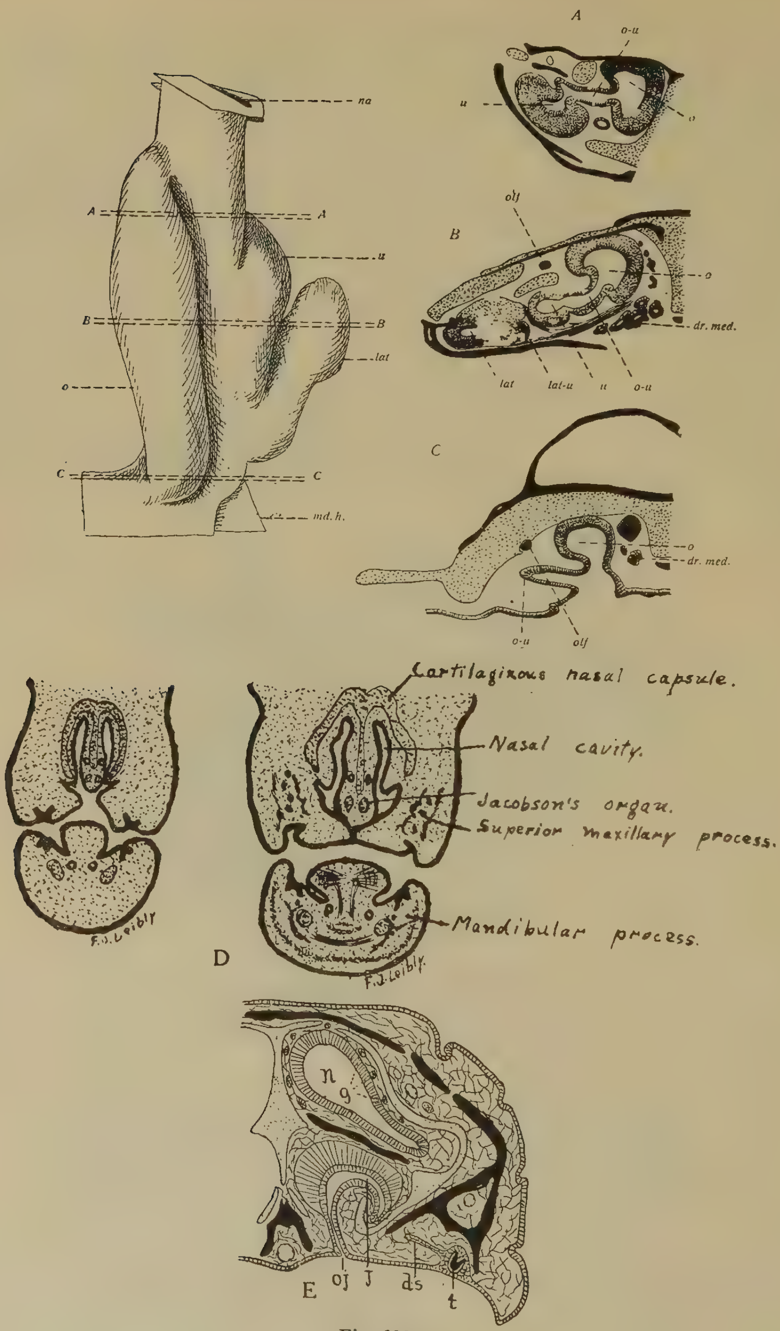


Fig. 339.

Reconstruction of smelling apparatus of Frog and three transverse sections (on the right) of tadpole through the regions marked *A A*, *B B*, and *C C*. *dr.med.*, glands on the medial side; *lat*, lateral view of the olfactory cavity; *lat-u*, com-

In the chick, and in fact in all vertebrates except the **Teleosts**, the lens forms as a hollow vesicle caused by the surface ectoderm invaginating. The choroid fissure of the optic cup closes a day or two before hatching. The closing begins opposite the pupil.

THE EAR

The auditory placode appears just as the neural folds close. These placodes then become depressed below the surface of the head and invaginate to form the **auditory sac** or **otocyst.**

This sac at the time of hatching has become completely closed and separated from the ectoderm from which it arose. Therefore, it comes to lie in close relation to the lateral surface of the medulla.

The superficial layer of ectoderm continues to remain as a covering of the region where the placode invaginated. The wall of the auditory sac is but one cell in thickness, except in the medio-ventral region. It is in this region that the ganglionic part of the placode is located. There is a small finger-like outgrowth from the sac, which extends dorsally from the medio-dorsal region. This is to become the **endolymphatic duct.**

There is little change in the ear region from this time to the opening of the mouth, that is, until the tadpole is ten to twelve millimeters in length. Then development seems to begin again.

The remaining complicated changes in the formation of the inner divisions of the ear are beyond the scope of this book. The VIII cranial nerve connects with the ear.

THE NOSE

The olfactory organs appear quite early, in fact before the brain closes (Fig. 339, *na*). A pair of ectodermal thickenings appears on each side of the head just above and anterior to the future mouth region. Again, only the deeper nervous layer is involved, as with the formation of the ear; only in this case, the superficial layer of ectoderm does not remain as a covering but disappears entirely. The thickenings themselves lie immediately anterior to the lens placodes, and are called **olfactory placodes.**

The placodes invaginate, forming the **olfactory pits** which are later to become the true nasal cavities (Fig. 339). A few cells from the inner surface of the olfactory placode become detached and come into communication with the surface of the fore-brain to form a sort of crest-

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munication of the lateral and lower region of the olfactory cavity; *md.h.*, wall of the mouth-cavity; *na*, external nares; *o*, upper region of the olfactory cavity; *olf*, olfactory nerve; *o-u*, communication between the upper and lower regions of the nasal cavities; *u*, lower region of the nasal cavity. (After Bancroft.)

D, Frontal section of human fetus of 29 mm. (After Tourneux.)

E, Sections through the nasal region. Bone black and cartilage dotted. *ds*, den-shelf; *g*, Jacobson's glands; *j*, Jacobson's organ; *n*, main cavity of nose; *oj*, opening of Jacobson's organ; *t*, tooth-germ. (After Schimkewitsch.)

ganglion. It is from these cells that the sheath cells of the true olfactory nerves (I cranial nerves) seem to be formed, the olfactory nerves themselves forming from the sensory cells of the olfactory placode.

The **olfactory pits** are often said to form the **anterior nares,** while the openings from the anterior nares into the mouth cavity are called the **posterior nares, internal nares,** or **choanae,** all three terms meaning approximately the same thing.

The olfactory development is quite complicated and cannot be worked out in all details by the student in an elementary course such as this, but it is important that the main features be understood, so that light may be thrown upon later studies.

The epithelial lining of the olfactory pits forms a cavity on the dorsal side soon after hatching. This cavity then closes to form a separate dorso-lateral lobe, which disappears entirely as metamorphosis continues.

During metamorphosis, various thickenings and outpocketings appear in the olfactory organ, and there is a sharp bend in the main axis. The most important of the outgrowths is an extension from the ventral side of the olfactory chamber, where a solid mass of cells proliferates. This extended portion then acquires a cavity, grows rapidly, and turns transversely toward the medial side. This structure is to become Jacobson's organ (Fig. 339). A large glandular mass develops upon the medial end of this organ.

Opposite Jacobson's organ another growth appears which is non-nervous, that is, is not lined with nerve cells. This becomes a large sac, and the cavity of the sac is then added to the olfactory chamber. Still another growth appears anteriorly, close to the base of the olfactory duct. It is into this latter structure that the duct from the **lachrymal glands** enters. Still later (about the time of metamorphosis) a dorsal sac grows out from the medial and posterior walls of the tube.

During the late metamorphosis, the axis of the olfactory organ is sharply bent by the shifting of the internal nares, and other glands appear as outgrowths, both in the olfactory chamber and in the posterior walls of the internal nares.

THE SENSE ORGANS OF THE LATERAL LINE (Fig. 340)

In all gill-bearing animals, and in all animals that have gills at any time during their development, such as the frog, a series of sensory organs develop which are known as **lateral line organs.** These organs vary to a very considerable extent, but three or four of them are rather constant. These are: (1) the **supraorbital line,** which runs forward from the ear region over the eye to the tip of the snout. Twigs from the ophthalmic branch of the VII cranial nerve innervate it.

(2) The **infraorbital line,** which also runs from the ear region, but

passes under the eye to the snout. It is innervated by the **buccalis nerve** which is a branch of VII.

(3) The **hyomandibular line** runs along the jaw and operculum. This is innervated by twigs from the mandibularis externus, and finally, (4) **the lateral line proper,** which may be double. This extends back to the tail on both sides of the animal, being innervated by twigs from the lateralis, a branch of the X cranial nerve.

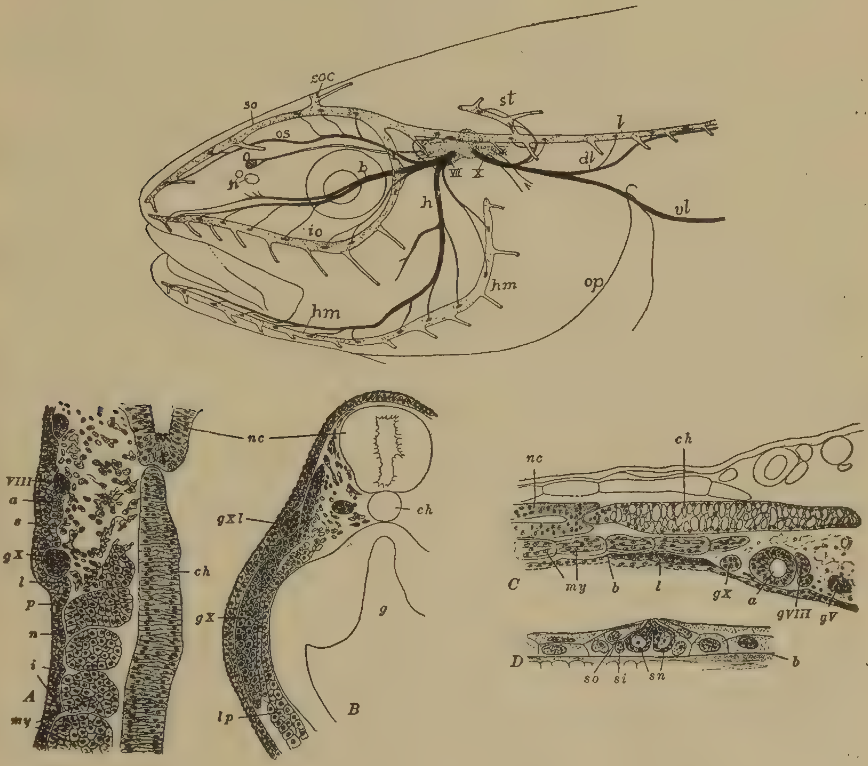


Fig. 340.

The development of the lateral line organs in *R. sylvatica*. *A*. Part of a frontal section through the level of the notochord of a 3.3 mm. embryo. *B*. Part of a transverse section through the vagus region of a 4 mm. embryo. *C*. Part of a frontal section through a 4 mm. embryo of *R. virescens*. *D*. Section through the lateral line organ of a 15.5 mm. larva of *R. sylvatica*. *a*, Auditory vesicle (in *A*, its rudiment); *b*, basement membrane of epidermis; *ch*, notochord; *g*, gut; *gV*, trigeminal ganglion, of V cranial nerve; *gVIII*, acoustic ganglion of VIII cranial nerve; *gX*, vagus ganglion; *gXl*, ganglion of the lateral nerve (branch of the vagus); *i*, intersegmental thickenings of the epidermis (ectoderm); *l*, rudiment of lateral line nerve; *lp*, lateral plate of mesoderm; *my*, myotomes; *n*, inner or nervous layer of epidermis (ectoderm); *nc*, nerve cord; *p*, pigment in epidermis; *si*, inner sheath cells of lateral line organ; *sn*, sensory cells of lateral line organ; *so*, outer sheath cells of lateral line organ. *E*, Lateral line canals and their nerves in a pollack (a fish belonging to the cod group). Canals and brain are dotted while the lateral nerves are black. *b*, buccalis ramus of the VII nerve; *dl*, dorsal ramus of lateralis of X nerve; *h*, hyomandibularis nerve; *hm*, hyomandibular line of organs; *io*, infraorbital line; *l*, lateral-line canal; *n*, nares; *o*, olfactory lobe; *op*, operculum; *os*, ophthalmicus superficialis nerve; *soc*, commissure which connects the lines of both sides; *so*, supraorbital line of organs; *st*, supratemporal part of lateral line *vl*, ventral ramus of lateralis of X nerve; *x*, visceralis portion of X nerve. (*A*. to *D*, from Harrison; *E*, from Kingsley after Cole.)

There may be also a **supratemporal line,** connecting the systems of both sides and extending across the posterior portion of the skull from one side to the other.

These lateral line organs sink beneath the skin, and usually degenerate in water-forms of animals as soon as they are ready to live on land. In a few cases such as **Tritons, Amblystoma,** etc., they are said to reappear when the animals return to water to deposit their eggs.

Various functions are assigned to these sensory line organs, but none has been clearly demonstrated. Probably they assist in recognizing differences in the vibrations of the water and may permit the animal to determine currents. They have been called a "sixth sense."

In the frog tadpole the sense organs of the lateral line are derived from the placode of the X cranial nerve. The **ramus lateralis** of the X nerve innervates the organ.

When the embryo is about four millimeters in length, there is a small dorso-lateral section of the vagus ganglion separated from (though lying close to) the ectodermal placode. The placode then begins to elongate posteriorly, while the deep cells proliferate rapidly to form a long, narrow tongue, which then pushes through the epidermis just outside the basement membrane. This tongue reaches as far back as the tip of the tail by the time of hatching.

Along this line, groups of cells form at intervals, each group representing the beginnings of a definite sense organ of the lateral line. In each group there are a few central sensory cells surrounded by a layer of enveloping cells. These groups then push up through the epidermis to the surface of the body, and the sensory cells develop hair-processes.

There are other tegumentary sense organs developing in definite rows on the head as well as dorsally from the mid-line to form those mentioned above, which are innervated by twigs from the VII, IX, and X cranial nerves.

All of the lateral line organs disappear, however, when the tadpole becomes an adult frog.

CHAPTER XLI.

THE DIGESTIVE TRACT

After the splitting of the mesoderm and notochord from the entoderm, the wall of the digestive tract is but one cell in thickness, except in the region of the mid-gut, where the yolk-mass is very large.

The stomodaeum, already discussed, is a shallow depression just below the olfactory and fore-brain region. This, by the time of hatching, while still very shallow, has its floor come to lie in contact with the wall of the fore-gut. The region in which these fuse is called the **oral plate** (Figs. 301, I, and 329, Pharyngeal membrane). It is at this point that the mouth forms a few days after hatching. The **oral sucker** (Fig. 337) forms just below the stomodaeal invagination.

The margins of the mouth form **mandibular ridges** which become drawn out as an upper and lower lip, the lower being the larger and freely movable. (Figs. 316, 317, 318.)

Strands of cells from the deep layer of the epidermis push toward the surfaces and as each cell arrives at the surface it becomes cornified into a so-called "tooth." The upper lip has three rows of these "teeth," while the lower has four rows. All of these are lost when the tadpole assumes its adult shape. In the adult form, true teeth and jaws form.

From the fore-gut the following structures are derived. (Figs. 328, 329, 337):

The Pharyngeal Cavity, the large expansion in the anterior portion of the fore-gut.

The Oesophagus, that portion of the fore-gut narrowed immediately dorsal to the yolk.

The Visceral Pouches are seen as vertical solid foldings extending to the surface ectoderm. Six pairs of these (compare this number with those found in the chick) develop, increasing in size and importance posteriorly.

The Visceral Arches, not to be confused with the pouches. **The arches** are the vertical rods of mesoderm lying between the pouches.

The hyomandibular pouch is the name given the first pouch.

The Mandibular arch is the first arch, lying in front of the hyomandibular pouch, or in other words, between the hyomandibular pouch and the mouth.

The I to V Branchial, or gill pouches, are the remaining ones running posteriorly from the **hyomandibular.** The hyomandibular is the first in point of position, but bears a separate name. The numbers thus begin with the true second pouch.

The Hyoid Arch is the arch lying between the hyomandibular and I branchial pouches.

Branchial Arches, or Gill Arches, are the names given to the remaining arches.

The Branchial Clefts, or Gill Clefts, are the names given the various pouches after they have opened to the surface of the ectoderm, and internally into the pharynx. The second and third clefts are the earliest to become perforated, while the hyomandibular pouch does not become perforated at all, but disappears shortly after the first perforations occur.

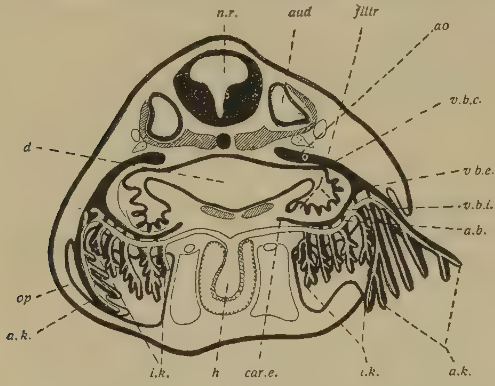


Fig. 341.

Ideal diagrammatic transverse section through a 13 mm. frog tadpole, showing the first gill arch.

The right side shows the external gills (*a.k.*) extending through the gill opening which is almost closed. As the opening closes the gills draw inward. On the left side the gill opening is wide open with the external gills showing themselves free. *a.b.*, the first gill artery; *a.k.*, external gills; *ao*, aortic roots; *aud*, otic capsule; *c.e.*, external carotid; *d*, pharynx; *s*, lumen of the intestine; *filtr*, anlage of the filter apparatus (gill rakers); *h*, heart; *i.k.*, internal gills; *nr*, anlage of the neural canal; *op*, gill operculum; *v.b.c.*, common branchial vein; *v.b.e.*, external branchial vein. *v.b.i.*, internal branchial vein. (After Maurer.)

The Eustachian tube or Tubo-tympanic cavity of the ear, forms from the dorsal wall of the hyomandibular pouch.

The External Gills (Figs, 337, 341), which appear just before hatching, are small outgrowths from the outer surfaces of the dorsal ends of the first and second branchial (second and third visceral) arches. A small external gill also appears later on the third branchial arch. The two anterior gills grow rapidly and form large lobed processes by the time the mouth opens. They become vascular and form the first breathing or respiratory organs of the tadpole. The posterior pair remain in a much more undeveloped state.

The Operculum (Fig. 341) is the name given to the covering of the external gills. It makes its appearance before the mouth opens, growing out from the posterior borders of the hyomandibular arches. These outgrowths extend backward so rapidly that by the time the anterior gills have reached their maximum size, the operculum covers them in what is called the **opercular cavity.**

The right opercular fold becomes fused with the body, while the left remains partly open to form the **opercular tube** or **spiracle.**

The Internal Gills form as tiny elevations on the postero-external faces of the branchial arches, just as the gill clefts are perforated. A thin layer of ectodermal cells covers them, just as it does the external gills. These gill coverings become doubled on the first three branchial arches and remain a single row on the fourth branchial arch.

The Gill Filaments are the branched processes of the gills which become quite vascular, and as they project into the opercular cavity, they permit the exchange of gases from the respiratory current of water entering the mouth, which current then passes through the gill clefts and the opercular tube.

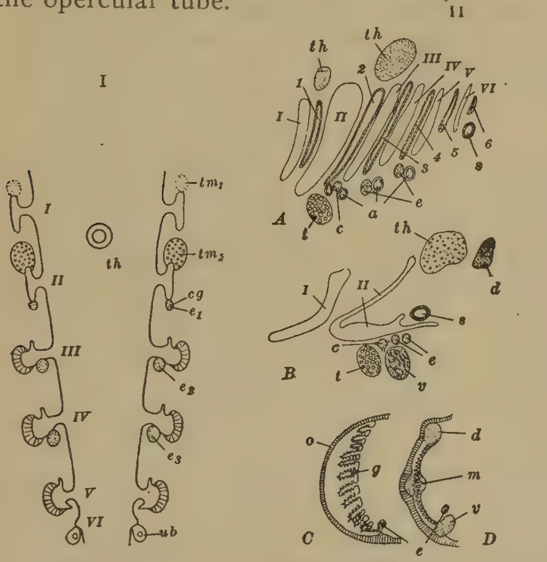


Fig. 342.

I. Diagram of the branchial pouch derivatives in the frog. (After Maurer, with Greil's modification.) *cg*, Carotid gland; e_1, e_2, e_3, epithelioid bodies; *th*, thyroid body; tm_1, tm_2, thymus bodies; *ub*, ultimobranchial body; *I-VI*, first to sixth visceral pouches. (*I*, hyomandibular; *II-VI*, first to fifth branchial pouches.)

II. Diagrams of the derivatives of the visceral pouches and arches in the frog. *A.* Lateral view, frog larva. *B.* Lateral view, after metamorphosis. *C.* Transverse section through gill of frog larva. *D.* Transverse section through gill region, just after metamorphosis; the gills have not quite disappeared. *a*, Afferent branchial arteries; *c*, carotid gland; *d*, dorsal gill remainder; *e*, epithelioid bodies; *g*, internal gills; *m*, middle gill remainder; *o*, operculum; *s*, suprapericardial or postbranchial body; *t*, thyroid body; *th*, thymus bodies; *v*, ventral gill remainder; *I-VI*, visceral arches; *I*, mandibular arch; *II*, hyoid arch; *III-VI*, first to fourth branchial arches; 1-6, visceral pouches; 1, hyomandibular pouch; 2, hyobranchial pouch; 3-6, first to fourth branchial pouches. (Greil's Modification of Maurer.)

The Velar Plates and Gill Rakers (Fig. 341, filtr) form as tiny folds in the pharyngeal region which can be best understood by a study of the cuts. (The velar plates are the smooth inturnings of the floor of the pharynx while the jagged tooth-like foldings are the gill rakers.)

The structures mentioned above are practically lost when the frog reaches adultship, although portions of these structures are used in building and forming other structures which will be discussed shortly.

The thymus body (Fig. 342) appears just prior to hatching. It is a solid internal proliferation from the epithelium of the upper side of the first branchial pouch (second visceral, or hyobranchial pouch). There is also a similar outgrowth from the hyomandibular pouch, but this disappears in a short time. The outgrowth which is to become the thymus grows slowly and separates entirely from the wall of the pouch when the tadpole is about twelve millimeters in length.

Both permanent and transient thymus bodies lie close to the outer surface of the head, immediately behind the auditory capsule and the articulation of the jaw.

Epithelioid bodies are similar to the thymus glands. These are formed from the **dorsal ends** of the other branchial clefts and become lymphoid in character.

The Carotid Glands form from the ventral ends of the **anterior gill pouches** as epithelial proliferations at about the time the internal gills appear.

The Pseudothyroid Body is a small outgrowth in the **postero-ventral branchial region,** apparently having no relation with the disappearing gill-clefts. This body disappears with the exception of traces of the middle and ventral portions, which persist for a short time after metamorphosis, but then they, too, disappear.

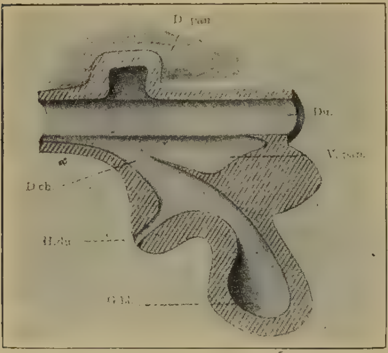


Fig. 343.

From a model of the duodenum and the primary evaginations of the liver and pancreas in a 5 mm. sheep embryo. *D.pan.,* Dorsal pancreas; *Du.,* duodenum; *D.ch.,* ductus choledochus; *G.bl.,* gall bladder; *H.du.,* hepatic duct. (After Stoss.)

The Ultimobranchial Bodies (also called post-branchial or suprapericardial bodies) lie posterior to the fifth visceral pouch. They have formed as solid proliferations from the pharyngeal wall just behind the visceral (fifth) pouch, (fourth branchial pouch). These bodies are supposed to represent vestigial portions of a sixth pair of visceral pouches, although they do not extend to the surface ectoderm. They separate from the pharynx and acquire a lumen, coming to lie on the floor of the pharynx in a suprapericardial position. (Fig. 342.)

The Thyroid Body is formed as a medial invagination from the floor of the pharynx just a short time before hatching. It forms as a solid rod of cells, but a few days after the opening of the mouth it forms a pair of bodies which grows very rapidly and becomes very vascular. The thyroid body has no genetic relationship to the branchial structures nor do any of the following structures possess such relationship.

The lungs. These develop just before hatching as a pair of solid proliferations from the ventral wall of the posterior portion of the fore-gut, just between the yolk-mass and the heart. The cavities begin to form in the proximal region.

The Laryngeal Chamber (Fig. 332, B) is formed by the wall of the fore-gut between and around the lung diverticula which become depressed and form a groove, which then (at least partially) constricts off from the alimentary tract.

The Glottis is the opening which remains in the laryngeal chamber as it constricts.

The Tongue appears just before metamorphosis as an elevation in the floor of the anterior portion of the pharynx, just behind the thyroid region. There is a glandular depression directly in front of the elevation which is carried forward by the anterior growth of the tongue, so that the glandular portion becomes the tip of the tongue.

The Liver is one of the earliest diverticula of the alimentary tract, appearing even before the embryo itself has begun to elongate. It lies beneath the yolk mass and develops from the ventral portion of the fore-gut, just posterior to the heart. A group of scattered mesodermal cells lies between liver and heart, which will soon be added to the anterior wall of the liver rudiment. The anterior portion of the liver becomes folded after hatching.

The Gall-bladder is formed as a postero-ventral extension of the liver diverticulum which becomes more or less separated from the anterior portion of the liver.

The Bile-duct (Fig. 332) is the original opening of the liver diverticulum into the alimentary tract from which it grew.

The Pancreas (Figs. 343, 293) develops in close proximity to the liver diverticulum from three separate rudiments, a dorsal and two ventral. The dorsal rudiment is a solid outgrowth from the dorsal wall of the fore-gut. A complete separation between outgrowth and origin soon takes place.

The right and left ventral rudiments grow out of the fore-gut at the posterior margin of the bile-duct. These retain their connection with the gut, enlarge, and after passing around the bile-duct, fuse together in front of it. The dorsal portion later also fuses with this fused right and left portion and connects with the gut by the pancreatic duct. At this period, the pancreatic duct forms the boundary between the fore-gut and the mid-gut, although later the pancreatic duct comes to lie within the margin of the bile-duct. Oesophagus and stomach develop quite as they do in the chick. It will be remembered that the oesophagus closes for a time in the chick. It does likewise in the frog just after hatching, when the tadpole is about eight millimeters in length.

The oesophagus, however, again opens just before the mouth is formed, that is, when the tadpole is about ten or eleven millimeters long.

The stomach is at first longitudinal, but it soon bends, and comes to lie transversely, a matter of importance when nerves are to be traced, for the nerves and blood vessels which are paired and known as right and left will now be dorsal and ventral, depending upon the side toward which the caudal end of the stomach turns.

THE DERIVATIVES OF THE MID-GUT

As with the chick, the mid-gut is confined to that more or less central space where the yolk continues being absorbed and converted into other substances in the growing embryo and tadpole. After hatching, the yolk is absorbed very rapidly, some of the yolk-cells becoming the epithelial lining of the growing intestine. The intestine is bent into a transverse loop called the **duodenal loop,** with its proximal end at the posterior portion of the stomach. In fact, the intestine grows to almost nine times the length of the tadpole's body, but is shortened later to about one-third the body-length by the time metamorphosis takes place.

The Hypochordal rod is a structure which forms from the mid-gut as a medial ridge along the surface of its entodermal wall just underneath the notochord, although it has no relation to the notochord. It appears when the tadpole is three or four millimeters in length, and extends both cephalad and caudad, coming to lie free of the gut wall when the tadpole reaches a length of about 4.6 millimeters. Finally, it can be seen as a caudal extension from the dorsal pancreas posterior through the tail. The rod itself is narrow, being only two or three cells in diameter. Just before the opening of the mouth, it breaks into pieces and disappears entirely.

THE DERIVATIVES OF THE HIND-GUT

It is in this region that the neurenteric canal is found (Fig. 328), as well as the proctodaeum. The terminal end of the hind-gut, which is to become the rectum, fuses with the proctodaeum, and the anal opening perforates the thin sheet which has separated these two structures. This fusion and perforation takes place at about the time the tail begins to elongate, namely, when the embryo is about four millimeters in length. It is the proctodaeal region of both tadpole and frog which forms the **cloaca** into which rectal, excretory, and reproductive ducts enter. **The Bladder** forms as a ventral outgrowth from the cloaca just before metamorphosis.

The Post-Anal gut is formed by the true hind-gut remaining within the embryo body proper as the tail continues growing. The nerve cord and notochord, however, are carried along in the growing tail so that the neurenteric canal is drawn out caudad. This neurenteric canal is then cut off from the nerve cord, but for a short period its antero-ventral portion opens into the rectum and it is this which is known as the post-anal gut. This gradually closes, although a strand of cells can still be seen in the region at the time of hatching, extending nearly to the tip of the tail. It finally disappears altogether.

CHAPTER XLII.

THE MESODERMAL SOMITES

All the remaining systems to be described are intimately related to the mesoderm.

The mesodermal region, in the chick, posterior to the head, divides into block-like segments by the formation of connective tissue septa which form at right angles to the long axis of the embryo. So, too, in the frog embryo and tadpole, the mesoderm divides into block-like segments. These are the **somites.** And, just as with the chick, so with the frog embryo, the mesoderm divides into an outer **somatopleure** and an inner **splanchnopleure layer** with an open space between them known as the **myocoele.**

That portion of the somites which lies directly on each side of the notochord is known as the **segmental or vertebral plate,** while the portion extending laterad from this segmental plate is called the **lateral plate.**

The lateral plates are therefore merely direct continuations of the segmental plates. However, as the somites divide off into blocks, the vertebral plates become thickened and not only is the myocoele closed which lies within them, but a constriction along the long axis of the embryo separates the vertebral plate from the lateral plate.

As there are no somites in the head region, the mesoderm lies in the form of scattered groups of mesenchymal cells in the head and pharyngeal regions.

The somatopleure and splanchnopleure are not of equal thickness. The outer somatopleure is only one cell in thickness, while the inner splanchnopleure is much thicker. Therefore, the coelom which lies between these two layers, lies much closer to the outer portion of the embryo than to the inner portion.

The one cell-layer which forms the outer somatopleure in the region where the somites have formed is naturally segmented, as that layer is an actual portion of the somite proper. These one cell-layered segments of somatopleure are now called **dermatomes** or **cutis plates,** because they will soon join with the ectoderm lying immediately above them to form the outer wall of the embryo.

The segments of the splanchnopleure which lie toward the center of the embryo are called **myotomes,** or **muscle plates,** because it is from these that the muscle cells will form. In fact, the formation of the muscle fibrils can already be observed when the embryo is scarcely five millimeters in length.

It is the thickening of the myotomes which obliterates the myocoele quite early.

From the lower ends of each myotome, that is, from those regions lying ventral and close to the mid-line, cells proliferate and move downward beneath the notochord as well as upward between the notochord and the myotome. These proliferations form the **sclerotomes** which are to become the cartilaginous vertebral column.

Very early, that is, when the tadpole is only about five millimeters long, the somite proper separates from the lateral plates, and the sclerotomes separate from the lateral plates.

Immediately after this separation, there are ventro-lateral outgrowths from both myotomes and dermatomes. Those from the myotomes become the ventral musculature and extend into the limbs as voluntary muscles, while that from the dermatomes break up into groups of mesenchymal cells, some of which become connected with the inner surface of ectoderm, and form the dorsal covering of the embryo, while some pass between the myotomes to form the connective tissue **septa,** also called **myocommata.** (Fig. 423.)

There are thirteen pairs of somites formed in the trunk of the frog, the two most anterior pairs disappearing in the adult. The full-fledged frog, therefore, has but eleven definite segments. The two anterior somites become part of the occipital region of the head. In the tadpole, there are many more somites than the amount stated above, but with the loss of the tail and the conversion of tadpole into frog, these are lost.

The following table will not only summarize the history of the somites and spinal nerves, but if carefully studied will show how the adult vertebral musculature which connects the posterior half of one vertebra with the anterior half of the next succeeding one, receives its innervation from more than one spinal nerve. A clear understanding of this will help the student very materially in his comparative anatomy. (See Fig. 336 also.)

TABLE OF SOMITES, VERTEBRAE, AND RELATED NERVES OF THE TADPOLE

(From Kellicott, after Elliot.)

Cartilaginous Elements in Sclerotome	SOMITES		NERVES
	Embryo	Adult	Adult
Occipital Region of Skull	1	Absent (Disappears at formation of limbs)	Root of vagus nerve
	2	Absent (Disappears at formation of vertebrae)	No nerve. Ganglion in embryo only

	3	1		Ganglion and Nerve in embryo Absent in adult
1 Vertebra	4	2	1	Spinal Nerve (Hypoglossal)
2 Vertebra	5	3	2	Brachial Plexus
3 Vertebra	6	4	3	
4 Vertebra	7	5	4	to body wall
5 Vertebra	8	6	5	
6 Vertebra	9	7	6	
7 Vertebra	10	8	7	Sciatic plexus
8 Vertebra	11	9	8	
9 Vertebra	12	10	9	
Part of urostyle	13	11	10	to pelvic region

Even before the lateral plates are separated from the somites, there is a tendency to segment in the lateral plate itself, close to the somite. It is in this region that the excretory system is to be formed, and so these portions are called **nephrotomes,** or the **intermediate cell mass.** (Fig. 268.)

This mere trace of segmentation in the lateral plate lasts a very short time. In fact, the lateral plate itself never segments.

The cavity within the lateral plates is the true coelom; and, just as in the chick, when the lateral plates extend further and further ventrally, they finally meet in the midline and fuse, thus making a single coelom where there had been one on each side before.

This ventral fusion forms the **ventral mesentery,** which soon disappears except in the heart region. The paired coelomic cavities also come together dorsally between the notochord and the digestive tract, and fuse to become the **dorsal mesentery,** which remains as a **suspensory arrangement** for the gut (Fig. 293). The gut itself later sinks more and more ventrally and the mesentery is pulled ventrad with it. The blood vessels supplying the digestive tract then grow downward through these two layers of mesentery.

CHAPTER XLIII.

THE CIRCULATORY SYSTEM

THE HEART

Immediately cephalad to the liver, just ventral to the hinder part of the pharynx (Fig. 328), is the heart region. Here the somatic and splanchnic layers of mesoderm have separated by a wide cavity which is to become the pericardial cavity (Fig. 344), continuous for a time with the general body cavity, but later closed off.

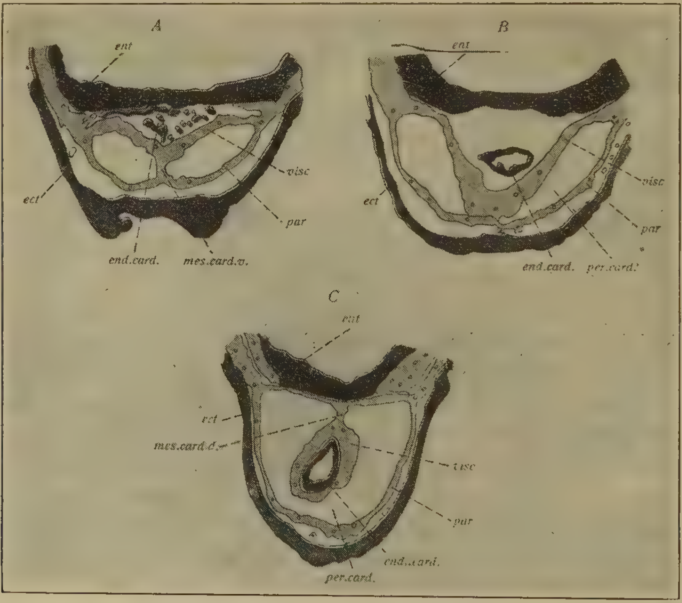


Fig. 344.

Cross sections of frog tadpole. *A* and *B* in the region of the anterior and posterior portions of the heart respectively; *C*, through a more or less mid-section of a more advanced tadpole, for comparative purposes. *ect*, ectoderm; *end.card.*, endocardium; *ent*, entoderm; *mes.card.d.* and *mes.card.v*, dorsal and ventral mesocardium; *par*, somatic layer of mesoderm (somatopleure); *per.card.*, pericardial cavity; *visc*, visceral layer of mesoderm (splanchnopleure). (From Rudneff.)

Both pericardial wall and muscular wall of the heart are derived from the lateral plate mesoderm, while the endothelium—the inner lining of the heart—arises from scattered mesodermal cells lying between the splanchnic mesoderm and the digestive tract. These cells can be seen in the two somite stage.

From Figure 344 one can get a good understanding of how the lateral plates extend beneath the pharynx and fuse in the midline to form the **ventral mesocardium.**

The splanchnic layer of the pericardium becomes folded dorsally so as to enclose the endothelial cells which have formed a more or less short tubular arrangement. Then the folds meet and fuse dorsally to form another tube on the outside of the endothelial tube. These latter tubes thus enclose the endothelial tubes, and are connected with the dorsal wall of the pericardial cavity. The connection forms the dorsal **mesocardium.** The outer tube forms the muscle of the heart walls.

Much difficulty will be avoided in our later studies if, after a review of the chick's circulatory system, the following account of the heart be mastered:

The paired endothelial tubes fuse together cephalad to form the **bulbus aortae.** Then there are outgrowths which form the beginnings of the **truncus arteriosus** or **ventral aortae.** The endothelial tubes do not fuse entirely in the posterior region, and are not alike on each side. The right one is bent and forms the beginnings of the **ventricle** and the **right vitelline vein.**

The left one is slightly longer and larger in diameter in the more caudal portion. This is to become the **auricle,** while its continuation in a caudal direction will become the left **vitelline vein.** Both vitelline veins are connected directly with the yolk-mass and the liver.

As the embryo develops, the two endothelial tubes fuse quite like the letter S, after which the dorsal mesocardium disappears, so that, as in the chick, the heart tube is attached only at its two ends.

The heart now comes to have its caudal end toward the left side and resting against the liver. This caudal portion is the region of the **sinus venosus** and the **auricles.**

However, as the heart continues growing much more rapidly than the surrounding portions, and as it is attached only at its two ends, the cephalic region of the heart and the ventricle region swing downward and come to lie ventral in position. This naturally forces the auricle dorsad, and the auricle thus comes to occupy the greater portion of the dorsal side of the adult heart.

Constrictions separate the heart early into two limbs, but it is only after the tadpole's mouth has opened that the auricle is divided into right and left halves by the **inter-auricular septum** which grows ventrad from the dorsal wall. The sinus venosus remains connected with the right auricle, while the pulmonary veins later enter the left auricle. The pulmonary veins can hardly be seen during the tadpole stage.

The ventricle walls thicken, and a few days after the mouth opens, the bulbus aortae divide into an anterior and a posterior portion. The anterior portion is called the **truncus arteriosus.** This truncus arteriosus is also divided into right and left channels.

THE ARTERIAL SYSTEM (Fig. 345)

The Lateral Dorsal Aortae, which are the first to appear, are paired and lie dorsal to the pharynx. They are formed from a series of separate spaces in the mesenchyme of the head region which then connect and form the vessels of the cranial region.

The Dorsal Aorta (Fig. 345, ao) is the name given the lateral dorsal aortae as soon as they fuse medially on the dorsal side of the embryo to form a single vessel. This vessel extends to the caudal extremity of the embryo.

The Aortic Arch. An aortic arch forms in each branchial arch, first as a little vascular space when the embryo is about 4.5 millimeters long. This space connects ventrally with the truncus arteriosus and dorsally with the lateral dorsal aorta (Fig. 341, ab). It is now called an **aortic arch.** Thus there are **four pairs** of these aortic arches, being in reality the third to sixth pair, and the first and second are formed in the mandibular and hyoid arches.

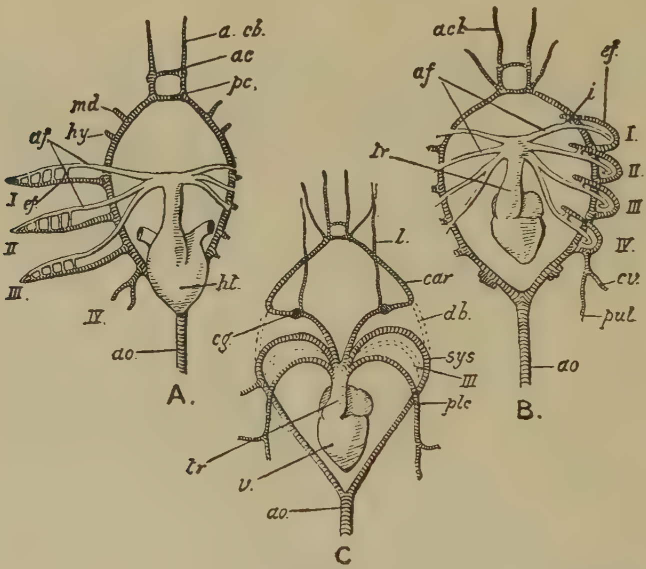


Fig. 345.

Diagrams of the heart and chief arteries of a tadpole. *A*, The vessels of a tadpole at the stage when three external gills are present; *B*, the arrangement when secondary gills are in use; *C*, the adult arrangement. *a.c.*, Anterior commissural vessel; *a.cb.*, anterior cerebral artery; *af.*, afferent branchial arteries; *ao.*, dorsal aorta; *car.*, carotid artery; *c.g.*, carotid gland; *cu.*, cutaneous artery; *d.b.*, ductus Botalli; *ef.*, efferent branchial arteries; *ht.*, heart; *hy.*, efferent hyoidean artery; *i.*, connecting vessel; *l.*, lingual artery; *md.*, efferent mandibular artery; *p.c.*, posterior commissural vessel; *pl.c.*, pulmocutaneous arch; *pul.*, pulmonary artery; *sys.*, systemic arch; *tr.*, truncus arteriosus; *v.*, ventricle; *I-IV.*, branchial aortic arches. (After Bourne.)

The Afferent Branchial Arteries (Fig. 345, af). As the external gills develop, a vessel forms dorso-laterally to the aortic arch, along the base of the gill to supply it. The vessel opens out of the ventral end of the aortic arch only to join it again at its upper end. The lower end of the aortic arch is then called the afferent branchial artery.

The Efferent Branchial Arteries (Fig. 345, ef). These are but the dorsal ends of the aortic arches. Loops of tiny capillaries formed in the external gill and connect afferent and efferent vessels. Later, after the external gills are lost and the internal ones developed, part of the aortic arches disappear, so that afferent and efferent vessels are connected by vessels of the internal gills. This causes the original aortic arch to become almost entirely an efferent branchial artery, while the vessel which connected ventral and dorsal ends of the aortic arch becomes the afferent branchial artery (Fig. 345).

As the internal gills disappear when the tadpole becomes a frog, the lower end of the efferent branchial artery, which is the original aortic arch, again acquires a direct connection with the afferent branchial artery so that the blood again passes from **truncus arteriosus** to dorsal aorta.

The gill capillaries diminish and the connection which has thus been re-acquired becomes larger, and forms the adult persistent vessels of the branchial arches. As the fourth branchial arch has no external gills developed upon it, the part described above regarding external gills does not apply to it. In all other respects, its blood supply is similar to those which do have external gills.

The above description applies to **Rana esculenta,** which, although different in detail, is essentially alike in all species.

The following account of the mandibular and hyoid vascular arrangement is for **Rana temporaria:**

Hyoidean Vein. This is a small outgrowth of the lateral dorsal aorta which extends toward, but never reaches the vessel which represents the aortic arch of the hyoid arch. It disappears at the time the mouth opens.

At the time of hatching there is a small outgrowth from the truncus arteriosus extending into the lower end of the hyoid arch, but this, too, disappears shortly, though it is at this time that the vestige of the aortic arch has already become divided into dorsal and ventral portions. The dorsal portion also disappears, and the ventral becomes the hyoidean vein. This disappears with the oral sucker.

Pharyngeal Artery. Just before hatching, the vessels of the mandibular arch appear. Here, too, there is a vestigeal aortic arch in the lower portion of the mandibular arch, which soon unites with an outgrowth from the lateral dorsal aorta. After union, this vessel joins the hyoidal vein.

After the mouth opens, the outgrowth from the lateral dorsal aorta separates from the other vessels, growing forward. It is then known as the **pharyngeal artery,** while, as mentioned above, the hyoidean vein disappears with the oral sucker.

The Anterior, or Internal Carotid Arteries (Fig. 345, car). These are the extensions of the lateral dorsal aortae into the head.

Commissural arteries (Fig. 345, ac). These are the two transverse connections between the internal carotids, which pass anterior and posterior to the infundibulum.

Lingual, or External Carotid Arteries (Fig. 345, l.). These appear before the time of the mouth opening as a pair of sinuses in the buccal cavity. As the mouth opens, they extend backward to connect with the ventral ends of the efferent branchial arteries of the first branchial arch at the point where the carotid gland is to develop.

Changes in Aortic Arches. As soon as the gills disappear, there must naturally be a great modification in the branchial aortic arches (Fig. 345).

Carotid Arch. As already stated, a continuous aortic arch is reestablished in each of the four branchial arches when the afferent and efferent arteries fuse. The first branchial aortic arch, which is the third arch of the entire series, remains as the **carotid arch.**

Systemic Arch. The lateral dorsal aorta between the carotid arch and the aortic arch immediately posterior to it, is reduced to a solid strand of connective tissue and no longer functions, so that the second pair of aortic arches (the fourth of the whole series) form the roots of the dorsal aorta and are called the systemic arches.

Pulmocutaneous Arch. The third aortic arch (the fifth of the whole series) also becomes a solid strand of tissue and then disappears entirely, while the fourth (the sixth of the whole series) becomes the pulmocutaneous arch.

Pulmonary Arteries. These appear just after hatching as small outgrowths from the upper ends of the efferent branchial arteries of the fourth branchial arch, which then extend backward to the lung rudiments.

Cutaneous Arteries. These leave the pulmonary arteries and extend dorsally to spread out over the skin of both sides and back.

Ductus Botalli. This, it will be remembered, from our study of the chick, is that part of the fourth aortic arch between the lateral dorsal aorta and the origin of the pulmonary arteries (Fig. 345). This portion slowly atrophies and also becomes a solid strand. Three channels are now formed in the truncus arteriosus by various septa which divide it longitudinally. The carotid arches lead from one of these channels, which receives blood from the left side, while another carries venous blood from the right side of the heart to the pulmocutaneous arches. The remaining one connects the systemic arches.

ORIGIN OF THE CIRCULATORY SYSTEM AND THE BLOOD

About the time of hatching, outgrowths of the dorsal aorta, just back of the pharyngeal region, extend laterally into the region of the pronephros or head kidney. These later become very large and form the vascular glomi of the kidney, traces of which remain long after the pronephros itself has disappeared.

The origin of the blood itself is by no means well established in the frog. The student should review the work on the chick in this respect. All we can say in regard to the frog is that when the embryo is almost ready for hatching, that is, when it is four to 4.5 millimeters in length, irregular spaces appear in the mesenchyme and splanchnic mesoderm, which later form continuous vessels. The corpuscles may arise as outgrowths from the endothelial lining of the blood vessels themselves, or from **blood-islands** which form on the ventral side of the yolk mass, or they may possibly form from both these sources.

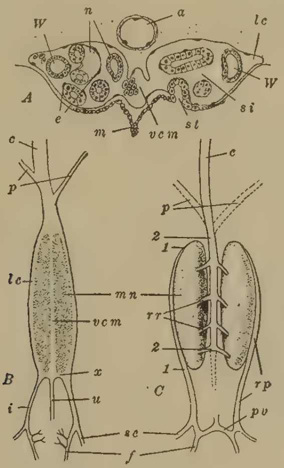


Fig. 346.

The development of the posterior part of the venous system in the frog. *A*. Portion of a transverse section through the posterior mesonephric region of an 18 mm. tadpole. *B*. Diagram of the veins of a 25-30 mm. tadpole. *C*. Diagram of the veins of the adult frog. *a*, Dorsal aorta; *c*, vena cava; *e*, nuclei of the endothelial lining of the mesopheric sinus, continuous with the vascular endothelium; *f*, femoral vein; *i*, iliac vein; *lc*, lateral mesonephric channel of the posterior cardinal vein; *m*, mesentery, *mn*, mesonephros; *n*, mesonephric tubules; *p*, posterior cardinal veins (in *C* showing their original location); *pv*, pelvic vein; *rp*, renal-portal vein; *rr*, revehent renal veins; *sc*, sciatic vein; *st*, nephrostome; *u*, caudal vein; *vcm*, median mesonephric channel of the posterior cardinal vein; *W*, Wolffian duct; *x* connection between caudal vein and the lateral mesonephric channels; 1-1, part of the renal-portal vein formed from the lateral channel of the posterior cardinal; 2-2, part of the renal-portal vein formed from the median channels of the posterior cardinal vein. (After Shore.)

THE VENOUS SYSTEM (Figs. 308, 346)

Omphalomesenteric, Vitello-intestinal, or Vitelline Veins. These veins are really the first part of the vascular system to form in the region of the blood-islands. They are paired but not alike on both sides. They pass along the lateral surface of the yolk and liver, and enter the sinus venosus. In fact, the sinus venosus is really formed by a fusion of these vessels from each side.

Ductus Cuvieri or Cuvierian Sinuses. These are a pair of large veins which enter into the sinus venosus also and may even form part of that organ. They come from the body-wall opposite the sinus venosus.

Hepatic Vein. As the liver develops, the omphalomesenteric veins which pass through that organ break up into capillaries within the substance of the liver. Then the parts of both omphalomesenteric veins, which lie between the liver and the heart, fuse into a single hepatic vein.

Hepatic Portal Vein. The right omphalomesenteric vein disappears caudad to the liver, while the left partly remains as the root of the future hepatic portal vein. This vein will later receive branches from the digestive tract as well as from those organs which have arisen from the digestive tract.

Anterior Cardinal Veins. As the ducts of Cuvier pass dorsad to the dorsal body wall, they divide. One branch passes headward as the anterior cardinal vein.

Superior Jugular Veins. This is the name given the anterior cardinal veins as they pass forward into the head, where they drain the brain and the dorsal portions of the head.

Inferior Jugular Veins. These drain the mouth, sucker, and ventral surface of the head, and open into the roots of the duct of Cuvier just before these in turn enter the sinus venosus.

Posterior Cardinal Veins. These are the posterior or caudal portions of the divided ducts of Cuvier, and are primarily the drainage system of the body-wall and excretory system. They pass caudad along the medial side of the pronephric ducts and receive the veins from the body-wall known as the segmental veins. The posterior cardinal veins form large sinusoids in the region of the pronephros, but as the metanephros develops, all this is modified, so that at fifteen millimeters the caudal ends of the veins fuse to form the single **median cardinal vein.**

Caudal Vein. This begins at the tip of the tail and drains that region. It is unpaired, but upon reaching the body cavity, divides above the cloacal region, and then empties into the posterior cardinal veins.

Posterior or Inferior Vena Cava, or Postcaval Vein. This begins as a branching of the left omphalomesenteric vein lying dorsal to the liver. From here, the postcaval vein passes through the suspensory fold of the liver to the right posterior cardinal vein and connects with it just anterior to the point where the median cardinal vein begins. This vessel enlarges rapidly and becomes the largest blood vessel in the body. It passes through the liver to the sinus venosus. The hepatic vein then opens into it instead of into the sinus venosus as formerly.

Anterior, Superior, or Precaval Veins. The pronephric portions of the postcaval veins degenerate as the pronephroi degenerate, and ultimately disappear entirely, even before metamorphosis is complete. These leave the ductus Cuvieri as the proximal portions of the anterior cardinal veins, and it is these remaining proximal portions which are called the anterior, superior, or precaval veins. All blood from the posterior parts of the body-wall and from the tail now passes directly to the heart through the median cardinal and postcaval veins.

Iliac Veins. The pronephroi are followed by the mesonephroi as in the chick, and an alteration in the relation of the median cardinal vein follows. On each side of the body the developing mesonephroi push into the median cardinal vein, so that this vein is divided into one median and two lateral parallel channels. The caudal vein empties into the median channel and finally disappears, and the iliac veins which come from the hind-legs open into the lateral channels. It is the iliac veins which become the chief vessels leading to the mesonephric region after the caudal vein disappears.

Adult Venous System. After an understanding of the formation and change which takes place in the venous system during the embryonic period, the adult system can be understood.

Afferent or Advehent Mesonephric Veins, or Renal Portal Veins. These are merely the iliac veins, together with the lateral channels of the median cardinal vein, with which they are continuous.

Posterior Vertebral Veins. These are the small veins from the posterior body wall which open into the renal portal vein.

Renal Veins, or Revehent Mesonephric Veins. These are the short connecting vessels which connect the vascular space in the mesonephroi with the median channel of the median cardinal vein, so that only this median channel remains as a posterior continuation of the postcaval vein.

Lateral Veins. A pair of these develop late in the ventral abdominal walls, and open into the sinus venosus. These connect with the iliac veins posteriorly, then fuse medially.

Anterior Abdominal Vein. The anterior ends of the lateral veins lose their connection with the sinus venosus, while the anterior portion of the right lateral disappears entirely. The left lateral vein forms a new connection with the hepatic portal vein, and is then called the anterior abdominal vein.

Pulmonary Veins. These can be seen when the tadpole is about six millimeters in length as projections of the endothelium on the dorsal side of the sinus venosus. These projections form a tube, opening proximally into the left side of the auricle, which distally leaves the wall of the sinus venosus, and passes dorsally to the lung rudiments. This tube bifurcates at the base of the lungs, where each branch then passes along the medio-ventral side of the lung rudiment. After the lungs begin to function, the pulmonary veins empty into the left auricle.

THE LYMPHATIC SYSTEM

By the time the tadpole is 6.5 millimeters in length, one may see a single pair of **"lymph hearts"** (Fig. 11). They are sac-like, and grow out of the **intersegmental veins,** usually from the fourth pair. That is, they are outgrowths from the veins which run between the fourth and fifth myotomes. These "lymph hearts" empty into the posterior cardinal veins at the more caudal end of the pronephros.

The "hearts" themselves lie between the peritoneum and the outer covering, and below the level of the myotomes. The endothelial lining of the "hearts" and the blood vessels is continuous.

The "beating" of the lymph hearts is due to a syncytial layer or network of striated muscle fibers immediately outside of the endothelium. The "beating" begins about the time the mouth opens.

A short time after hatching, that is, when the tadpole is about 7.5 to 8.0 millimeters in length, two lymphatic vessels develop from each heart. They are known as anterior and posterior lymph vessels. They follow the lateral nerve in direction, the anterior vessel extending into the head, and the posterior along the sides of the trunk. Valves guard the openings of the lymph vessels into the "hearts" as well as into the veins where they empty.

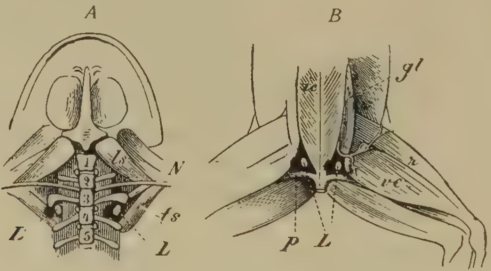


Fig. 347.

Frog. *A*, showing anterior lymph-hearts, from the dorsal side. *B*, showing posterior pair of lymph-hearts seen from the ventral side. *gl*, gluteus muscle; *ic*, iliococcygeal muscle; *L*, lymph-heart; *ls*, levator scapulae muscle; *N*, spinal nerve; *p*, piriformis muscle; *r*, vastus muscles; *ts*, transverse scapularis major muscle; *ve*, vastus externus muscle; 1-5, vertebrae. (After Wiedersheim.)

Immediately after these lymph vessels begin growing, they develop a rich network of capillaries which spread out in all directions, being greatest in number close to the skin. Later, as the tadpole becomes quite large (about twenty-six millimeters), the lymphatic system becomes well developed.

The anterior lymph vessel, running downward and forward, connects with a large **lymph sinus,** around the mouth, heart, and branchial region. The posterior vessel passes caudad into the tail, and there divides into dorsal and ventral branches. These dorsal and ventral branches of each side then unite to form two large vessels which extend through the tail, one of them above and the other below the myotomes. The walls disappear in the network that has grown out from the lymphatic vessels to form the large subcutaneous **lymph sacs** already noticed in the dissection of the adult frog.

The thoracic ducts extend posteriorly from the "lymph hearts" and are probably outgrowths from them. They lie between the dorsal aorta and the posterior cardinal veins.

The **posterior lymph hearts** (Fig. 347)—(one to three pairs in number)—develop from the intersegmental vein just as did the anterior hearts, but their development is postponed until the hind-legs appear.

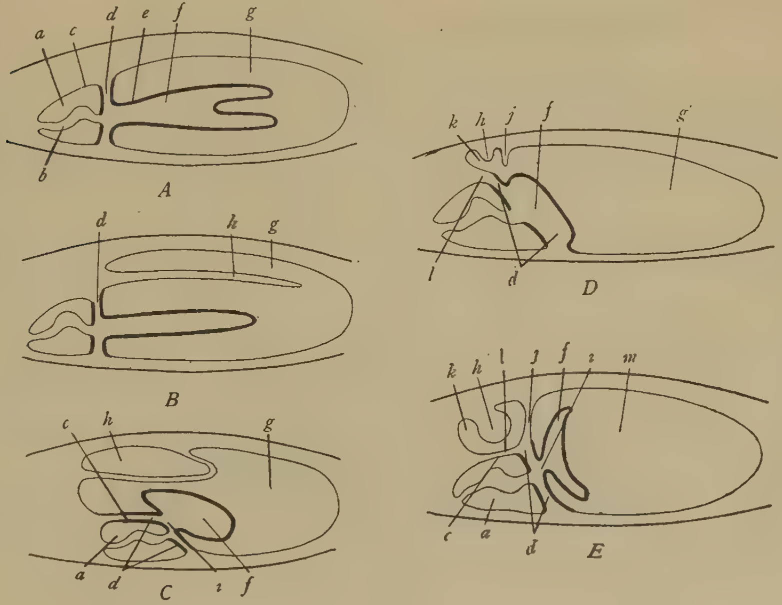


Fig. 348.

Diagrams to illustrate the divisions of the coelom in the various vertebrate classes. The transverse septum and its derivatives are indicated by thick lines. *A*, fishes, showing the division of the coelom into pericardial cavity *a*, and pleuroperitoneal cavity *g*, by means of the transverse septum *d*. *B*., urodeles; similar to fishes with the addition of the lung *h* which projects into the pleuroperitoneal cavity *g*. *C*, turtle; the pericardial cavity *a* has descended posteriorly until it lies ventral to the anterior part of the pleuroperitoneal cavity *g*; the anterior face of the transverse septum, *d*, has now become part of the wall of the pericardial sac; the lung, *h*, is retroperitoneal. *D*, early stage of Mammals, showing the beginning of the coelomic fold (pleuroperitoneal membrane), *j*, descending from the dorsal body-wall, and the liver, *f*, enclosed within the transverse septum, *d*. *E*, later stage of mammals, showing union of the coelomic fold, *j*, with the transverse septum *d*, the two together forming the diaphragm which separates the pleural cavity *k* from the peritoneal cavity, *m*; the liver has constricted from the main part of the transverse septum, the constriction becoming the coronary ligament, *i*, *a*, pericardial cavity; *b*, heart; *c*, parietal pericardium or pericardial sac; *d*, transverse septum; *e*, serosa of the liver, this being a part of the transverse septum originally; *f*, liver; *g*, pleuroperitoneal cavity; *h*, lung; *i*, coronary ligament of the liver; *j*, coelomic fold which forms part of the diaphragm; *k*, pleural cavity; *l*, pleuropericardial membrane or anterior continuation of the transverse septum; *m*, peritoneal cavity. (From Hyman's "A Laboratory Manual for Comparative Vertebrate Anatomy," by permission of the Chicago University Press.)

Their first openings are into the posterior cardinal vein, which means that later they empty into the renal portal veins.

The Spleen. This ductless gland is first seen in the developing tadpole at about ten millimeters. It appears as a mass of mesenchymal lymphoid cells in the mesentery, immediately dorsal and posterior to the stomach and around the mesenteric artery.

These cells then multiply and project from the mesentery so as to have a peritoneal covering, as do all the organs in the body cavity. Later, as the spleen enlarges, there seem to be various wandering cells from the intestinal epithelium added to it. The spleen is complete by the time the tadpole is twenty-five to twenty-seven millimeters in length and is extremely vascular.

THE SEPTUM TRANSVERSUM (Fig. 348)

The pericardial cavity, already discussed, has remained open posteriorly into the abdominal cavity, with the exception of the region covered by the liver. Now, as the ducts of Cuvier form and pass from the body-wall to the sinus venosus, they pass through this open region and carry with them incomplete peritoneal folds from the body-wall. These folds are called the **lateral mesocardia.** They remain incomplete dorsally for a long time, but gradually extend ventrally so as to form a complete separation between pericardial and peritoneal cavities. This transverse partition is called the **pericardio-peritoneal septum** or the **septum transversum.** To this septum transversum is added a medial portion of peritoneum from the anterior face of the liver, while on the right side the septum becomes continuous with the posterior suspensory fold of the liver commonly called the **mesohepaticum.**

After metamorphosis, the septum unites dorsally with the dorsal mesentery and completes the separation between pericardial and peritoneal cavities.

CHAPTER XLIV.

THE UROGENITAL SYSTEM

From our study of the urogenital system of the chick, we learned that while in birds and mammals, a pronephros, a mesonephros, and a metanephros form, in amphibians the first two forms of nephridic organs alone make their appearance, the mesonephros then remaining as the permanent adult functioning kidney.

We have already spoken of the **nephrotomes,** which are also called the **intermediate cell mass** (Fig. 268).

Some time before hatching, when the embryo is only about three to four millimeters in length, this intermediate cell mass can be seen as longitudinal thickenings on each side of the notochord. These thickenings then form a groove, the lips of which soon fuse to form a tube or duct. This is the **pronephric** or **segmental duct.** It is at the anterior end of this pronephric duct (in the region of the second to fourth somites) that the pronephros or head-kidney forms as a ventro-lateral outgrowth.

At this anterior end of the pronephric duct there are three tiny openings left as the lips of the duct fuse. These three openings become the three **pronephric tubules** (Figs. 349, 350), and the openings of these tubules into the coelom are called the **nephrostomes.**

The nephrostomes become lined with large cilia which produce a current out of the coelom, which current then passes by way of the pronephric duct to the cloaca.

The pronephros itself becomes quite vascular. In the discussion of the posterior cardinal veins, mention was made of the close relation of these veins to the excretory system. It will be remembered that they lie along the pronephric ducts. The elongating of the pronephric tubules pushes them upward into the posterior cardinal sinus until the sinus is nearly filled. This means, of course, that the tubules are really bathed in venous blood.

At the same time that this occurs, arterial blood is brought from the dorsal aorta to the excretory system by arteries in the form of glomeruli.

The manner in which the glomeruli form is rather complicated. Opposite the second nephrostome, a fold appears in the splanchnic mesoderm, when the embryo is about 4.5 millimeters long. This fold lies parallel to the pronephros itself, becoming elevated and projecting into the coelom opposite the nephrostomes. Vascular spaces appear in this fold, which develop the long convoluted vessels of the glomerulus proper, and also a definite vessel which connects with a branch from the dorsal aorta.

This region of the body cavity is later cut off from the **pronephric chamber** by the lungs, projecting laterally, and carrying a fold of peritoneum across to the peritoneum which covers the pronephros, fusing with it for a short distance. The pronephric chamber remains open into the coelom both anteriorly and posteriorly to the lung region.

The **pronephric capsule** is derived from two sources, namely: from

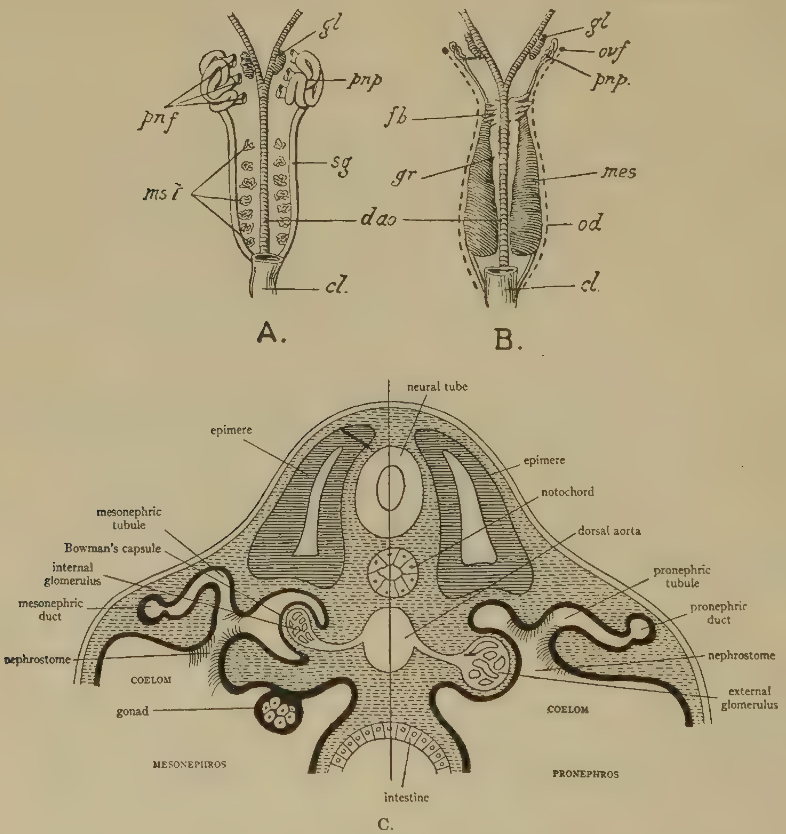


Fig. 349.

A and *B*. Diagrams of the development of the excretory system of the frog. *A*, The system of a tadpole about 12 mm, long, showing the pronephros and origin of the mesonephric tubules; *B*, the system at the end of metamorphosis. The broken line represents approximately the position of the strip of peritoneal epithelium which gives rise to the oviduct. *cl.*, Cloaca; *d.ao.*, dorsal aorta; *f.b.*, fat body; *gl.*, glomerulus; *gr.*, gential ridge; *mes.*, mesonephros; *ms.t.*, mesonephric tubules; *od.*, oviduct; *ovf.*, position of oviducal opening; *pn.f.*, pronephric funnels; *pnp.*, pronephros; *sg.*, segmental duct. (From Bourne.)

C, Diagram to show the structure of the pronephros and the mesonephros. Pronephros on the right and mesonephros on the left. The chief difference is in the relation of the glomerulus; in the pronephros it projects into the coelom; in the mesonephros it projects into the tubule, which forms the Bowman's capsule about it. (From Wiedersheim.)

the ventro-lateral walls of the myotomes, which normally give rise to mesenchyme but which here evaginate in the pronephric region over both dorsal and lateral surfaces of the head-kidney to meet with folds coming up from the somatic layer of the lateral plate. This forms a capsule of connective tissue which encloses not only the pronephros proper, but also the pronephric sinus of the posterior cardinal vein.

The pronephros is largest when the tadpole is about twelve millimeters long. It remains stationary until the twenty millimeter stage, when it begins to degenerate. Degeneration is not quite complete at metamorphosis. Various blind outgrowths of the three original tubules

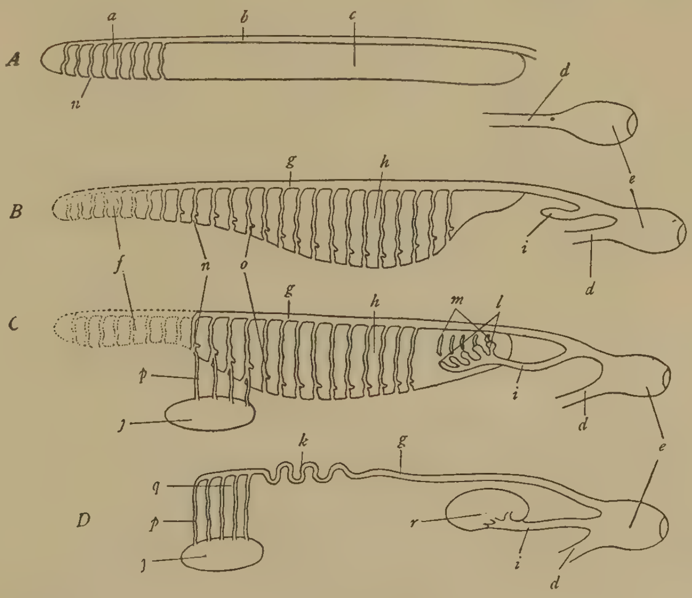


Fig. 350.

Diagrams to show the development of the three kidneys and their ducts and their relation to the male gonad. *A*, early stage showing the pronephros *a*, developing from the anterior end of the mesomere *c* and the pronephric duct *b*, which has not yet reached the cloaca *e*. *B*, next stage illustrating the degeneration of the pronephros at *f*, the development of the mesonephros *h*, from the middle portion of the mesomere, the junction of the pronephric duct, now the mesonephric duct *g* with the cloaca and the beginning of the metanephric evagination *i* from the mesonephric duct. *C*, later stage, showing connection between certain tubules of the mesonephros and the testis *j* by means of tubules, the vasa efferentia, *p*, which grow out from the mesonephros; and the penetration of the metanephric evagination into the posterior end of the mesomere where it is subdividing to form the collecting apparatus *l*, which becomes associated with the secretory metanephric tubules *m*, developed in the mesomere. *D*, final stage, in which the mesonephros has disappeared except for the remnant *q*, which connects with the testis *j* by means of the vasa efferentia *p*; the mesonephric duct *g* persists as the vas deferens; the two parts of the metanephros shown in *C* have united to form a single organ *r*. *a*, pronephros; *b*, pronephric duct; *c*, mesomere or nephrotome; *d*, intestine; *e*, cloaca; *f*, degenerating pronephros; *g*, mesonephric or Wolffian duct; *h*, mesonephros or Wolffian body; *i*, metanephric evagination from the Wolffian duct in *B*, ureter in *C* and *D*; *j*, testis; *k*, coiled portion of the vas deferens forming part of the epididymis; *l*, collecting part of the metanephros derived from the Wolffian duct; *m*, excretory tubules of the metanephros derived from the mesomere; *n*, nephrostome; *o*, renal corpuscle or Malpighian body; *p*, vasa efferentia; *q*, remnant of the mesonephros, forming part of the epididymis; *r*, metanephros. (From Hyman's "A Laboratory Manual for Comparative Vertebrate Anatomy," by permission of The Chicago University Press.)

can be seen before degeneration sets in. The pronephric duct closes just posterior to the pronephros, and the tubules break up and disappear.

The nephrostomes, however, approach one another, and finally meet to open into a common cavity called the **common nephrostome.** This, then, also closes so that the nephrostomes are entirely cut off from all communication with the body cavity. The glomeruli also disappear, although traces of these can still be seen for some months after metamorphosis.

THE MESONEPHROS OR WOLFFIAN BODY

Just about the time the pronephros attains its full size, or a little before, the mesonephros or Wolffian body begins to form in the region of the nephrotomes or intermediate cell-mass of the seventh to twelfth somites. It is both somatic and splanchnic in origin. These nephrotomes fuse in a continuous longitudinal strip of irregularly arranged cells which lie between the pronephric duct and the dorsal aorta, along the posterior cardinal vein. Little swellings appear in this mass, which are the beginnings of the **mesonephric vesicles.** They are more numerous than the mesodermal segments, and so are not strictly metameric.

Each of these swellings divides into a large ventral and a smaller dorsal chamber; the larger one being called the **primary mesonephric unit** and the smaller the **secondary mesonephric unit.**

The secondary units divide later to form a **tertiary** mesonephric unit.

Each of the three units develops much alike. Figures 349 and 350 show this development. There are two outgrowths, an **inner tubule** which grows dorso-laterally to the pronephric duct where it opens, and an **outer tubule** which grows ventro-medially to the peritoneum with which it fuses, and then it empties into the body cavity.

The inner tubules connecting with the mesonephric duct convert the portion where such connections are formed into the mesonephros or Wolffian body—the true kidney of the adult frog. The duct itself, in the region of the connections, is known as the **Mesonephric** or **Wolffian Duct,** while the duct posterior to this region is now the **ureter.**

The inner tubules become elongated and coiled to form the tubular portion of the mesonephros, while the outer tubules form outgrowths which later form the capsule around the glomeruli, known as **Bowman's capsules.**

A small twig from the dorsal aorta connects with each glomerulus in a similar manner to the way the glomeruli were formed in the pronephros. The proximal portion of the outer tubule, from which the outgrowths arise to form the capsule, now separates from the remaining tubule, but retains its connection with the inner tubule, and the distal portion of the outer tubule comes to lie in connection with the body cavity. This latter connection becomes ciliated and forms a typical nephrostome as in the pronephros. The nephrostomal region now forms another connection at its inner end with the sinus of the posterior cardinal vein, in which sinus the mesonephric tubules lie surrounded by venous blood.

Many, as high as two hundred, outer tubules and nephrostomes may be formed from the three units described, and possibly some may be formed also by independent evaginations from the peritoneum, or even by splitting of those previously formed.

The **urinary bladder** is a median ventral outgrowth from the wall of the cloaca nearly opposite the openings of the ureters.

THE REPRODUCTIVE SYSTEM

The mesonephric duct becomes divided somewhat obliquely into two portions in front of the mesonephros, the more anterior portion now being the Müllerian duct, while the posterior portion forms the Wolffian duct. The Müllerian duct connects with the peritoneal epithelium anteriorly and empties into the cloaca posteriorly. In the male frog, this duct persists as a mere longitudinal streak on the outer side of the kidney, and extends some distance in front of it. In the female frog, this Müllerian duct becomes the oviduct (Fig. 350).

The Wolffian duct functions as the ureter in both sexes, but in the male, the posterior end of it becomes dilated into a glandular enlargement called the **seminal vesicle.**

Already at the six millimeter stage, as the mesentery is being formed by the coming together of the somites from both sides just under the dorsal aorta, a small group of entodermal cells is pinched off from the yolk, which, after completely separating from the yolk, divide longitudinally, each half moving laterally. These longitudinal halves are the **genital ridges** (Fig. 349, B). They lie close to the mesenteric attachment, and just beneath the cardinal veins.

The genital ridges become quite conspicuous in a short time by germ-cell proliferations as well as by the peritoneal cells which cover them, and the mesenchymal cells from the body wall which migrate to this region.

The mesenchymal cells form the **stroma** of the ridge; the peritoneal cells form a thin superficial covering at first, while later they also form the suspending folds (**mesorchia** of the testes, and **mesovaria** of the ovaries) of the gonads. The germ-cells now begin to proliferate and form the **nests of cells** (Fig. 254), which are to develop into gonads and gametes as already described early in the embryology of the chick.

The anterior portion of the genital ridge becomes the **fat body** shortly before metamorphosis, while the posterior portion connects with the mesonephric duct.

In this posterior region several outgrowths from the Malpighian bodies known as **sexual cords** can be seen. These become tubular, and extend into the substance of the gonad. In the male, these sexual cords, after metamorphosis, form the **vasa efferentia** or **efferent ducts** by which spermatozoa are carried from the gonad proper to the real sperm duct, the **vas deferens.** In the female, the portions between ovary and mesonephros degenerate, remaining only as a vestige, called **Bidder's organ** (Fig. 457).

The tadpole must be of considerable size before the sexes can be distinguished, Bouin giving the length as thirty millimeters in **Rana Temporaria.** In the male gonad, the cells all look alike, while in the female gonad, the follicle arrangement can be made out, and the ovary acquires a central lumen.

THE ADRENAL BODIES OR EPINEPHROI

Figure 351 will show how the adrenal bodies grow on the mesonephros of the frog. The important point to remember is that **there are two kinds of cellular substances in these organs.** The adrenal bodies lie on the ventral surface of the mesonephros in the frog.

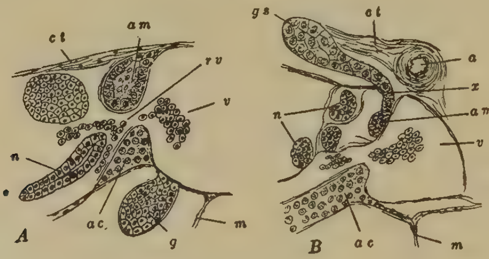


Fig. 351.

Parts of sections through young *R. temporaria*, showing the origin of the adrenal bodies. *A.* Through 30 mm. tadpole. *B.* Through 11 mm. frog after metamorphosis. *a*, Dorsal aorta; *ac*, cortical cells of adrenal body; *am*, medullary cells of adrenal body; *ct*, connective tissue; *g*, gonad; *gs*, sympathetic ganglion; *m*, mesentery; *n*, mesonephros; *rv*, revehent renal vein; *v*, vena cava; *x*, point where ganglion cells enter mesonephros and adrenal body. (After Srdinko.)

Histologically, one may see a coarse network of cell strands with occasional groups of darkly staining tissue called **phaeochrome tissue.** Blood from the median posterior cardinal vein occupies the spaces in the adrenal body. The coarse network forms what is called the **cortical** tissue, and the more darkly staining portions are known as **medullary** tissue, because in the higher forms of animal life, the darkly staining portion lies toward the inner region of the organ, and the coarse network lies toward the outer or cortical region.

When the tadpole is about twelve millimeters in length, the cortical region appears as small groups of cells lying along both sides of the wall of the median posterior vein, below the level of the mesonephros, as well as beneath the peritoneal epithelium from which they seem to arise.

Just after metamorphosis, these cell-groups separate from the peritoneum to form the network mentioned.

The medullary portion, however, has a totally different origin, and one which may throw light on further work in our study of ductless glands, whose secretions have become an important factor in modern medicine. This portion is derived **from the ganglia of the sympathetic nervous system** by groups of cells whose precise origin is not clear. Some of these cell groups remain in the sympathetic ganglia, but others migrate to the adrenal body and become scattered about.

CHAPTER XLV.

THE SKELETAL SYSTEM

The notochord extends from the blastopore to the pituitary body, as a rod of vacuolated cells filled with fluid, around which three layers or sheaths form.

The **primary,** or **elastic sheath,** is an outgrowth of superficial cells of the notochord itself and forms the superficial surface sheath of the notochord.

The **secondary** or **fibrous sheath** is formed between the primary sheath and the notochord also by cells from the notochord itself.

The third, or **skeletogenous** sheath, forms on the outside of the primary layer at a later period as a thin sheath which is formed by the **sclerotomes.** The sclerotomes, it will be remembered, are outgrowths from the somites. This skeletogenous layer extends dorsally, entirely around the neural tube, and laterally, from the notochord, in between the successive myotomes. It is in this skeletogenous layer that the vertebrae are to be formed.

When the tadpole is about fifteen millimeters long, a series of metameric cartilages can be observed along the medio-ventral surface of the notochord. They lie in the skeletogenous sheath (Fig. 352, cs). These segments fuse longitudinally to form a pair of dorsal and ventral strips which extend along the entire notochord.

These strips now become metameric by constrictions of fibrous tissue which form rings. The rings are the beginnings of the **inter-vertebral ligaments,** which, just as in the chick, appear opposite the middle of each mesodermal segment.

The mesodermal segments become the vertebrae, so that the ligaments which form as separate segments between the vertebrae, are able to act on both the vertebra lying immediately anterior and immediately posterior to each mesodermal segment, after the muscle has developed in connection with these ligaments (Figs. 305, 352).

The notochord becomes segmented and surrounded by cartilage, the notochordal segments form the soft centrum of the vertebrae, and probably also portions of the intervertebral discs.

The ventral cartilages now grow around the sides of the notochord and meet to fuse with the dorsal series.

The **transverse processes** of the vertebrae grow out from the ventral cartilages. It is toward the lateral ends of these that the transverse processes of the ribs later develop.

The **neural arch** is formed from outgrowths of the dorsal series which grow inward beneath the neural cord and also dorsally and ventrally. Later, when ossification begins, short processes called **intervertebral articulatory processes** develop from the neural arches, by which each vertebra joins with the next succeeding vertebra.

Ossification begins in the tadpole between the dorsal and ventral series of cartilages just described. There are nine vertebrae formed in the frog, plus the urostyle, the latter being unsegmented.

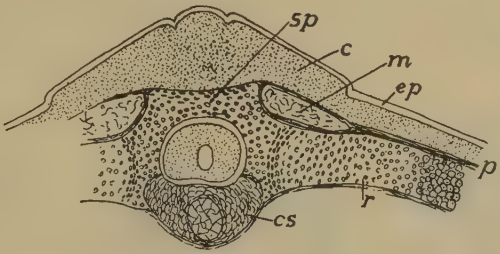


Fig. 352.

Cross section through a developing vertebra, rib and exoskeleton of a Turtle. *c*, corium in which the dermal plates are developed; *cs*, primitive vertebral body; *ep*, epidermis; *m*, external oblique muscle; *p*, perichondrium; *r*, rib; *sp*, spinous process. (From Kingsley after Götte.)

THE SKULL

The skull is commonly formed from various embryological **elements**, which may be listed as follows:

(1) Cranium.
(2) Sense Capsules.
(3) Visceral Arches.
(4) Notochord.
(5) Vertebrae.
(6) Membrane or Derm Bones.

It will be remembered that there are no true segments in the head region of the frog. Consequently, the list just given is only **assumed from a comparison of other forms.**

When the cranial region begins its cartilage formation, the tadpole is about seven millimeters in length. A pair of dense strands of tissue form along the ventro-lateral surfaces of the fore-brain. These then become cartilaginous and form the beginnings of the **trabeculae,** or **trabecular cartilages** (Fig. 310). These trabeculae extend forward and fuse across the midline between the olfactory organs. The fusion forms the **internasal plate.** The trabeculae continue extending forward, and these extensions are known as the **trabecular cornua,** at the ends of which the **olfactory capsules** form.

A pair of **labial** or **suprarostral cartilages** which have formed in the upper lip meet with the olfactory capsules.

The notochord which extends into the brain up to the pituitary body has a pair of tissue thickenings beginning in the region of the hind-brain and extending anteriorly as **parachordae,** or **parachordal cartilages.** These parachordal cartilages now fuse with the posterior ends of the trabeculae to enclose the tip of the notochord, and the entire continuous plate beneath the fore-brain is then called the **parachordal plate.**

These parts can be made understandable only by a careful examination of Figures 310 and 353, which must be studied with great thoroughness or much of our later work in comparative anatomy will be valueless.

From the visceral arches, the **palato-quadrates** are formed as a pair of flattened rods, lateral to the trabeculae. These are in intimate relation to the cranium proper. They connect with the trabeculae by **anterior ascending processes** back of the olfactory region, and by **posterior ascending processes** opposite the end of the notochord.

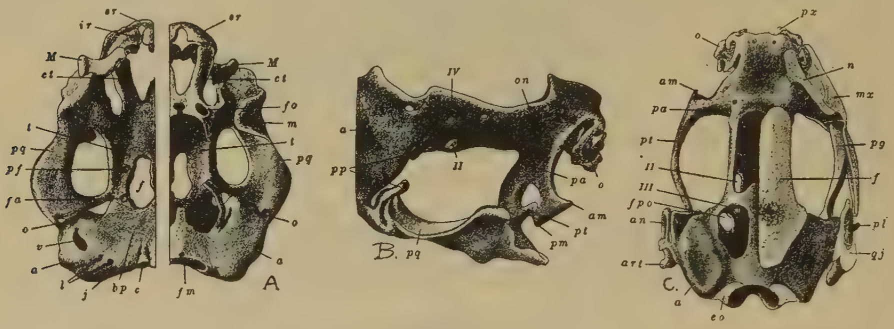


Fig. 353.

A. Chondrocranium of 29 mm. larva of *R. fusca.* To the left, the ventral surface; to the right, the dorsal surface. *a,* Auditory capsule; *bp,* basal plate; *c,* notochord; *ct,* trabecular cornu; *f,* basicranial fontanelle; *fa,* foramen for carotid artery; *fm,* foramen magnum; *fo,* foramen for olfactory nerve; *ir* infrarostral cartilage; *j,* jugular foramen for IX and X cranial nerves; *l,* perilymphatic foramina; *m,* muscular process; *M,* Meckel's cartilage; *o,* otic process of palato-quadrate; *pf,* palatine foramen; *pq,* palato-quadrate cartilage; *sr,* suprarostral cartilage; *t,* trabecular cartilage; *v,* secondary fenestra vestibuli. *B,* Anterior portion of chondrocranium of *R. fusca* during metamorphosis. Lateral view. *C.* Skull of 2 cm. *R. fusca,* after metamorphosis. Dorsal view. Membrane bones removed from left side. *a,* Auditory capsule; *am,* anterior maxillary process; *an,* annulus tympanicus; *art,* articular process of palato-quadrate cartilage; *eo,* exoccipital bone; *f,* fronto-parietal bone; *fpo,* proötic foramen; *mx,* maxillary bone; *n,* nasal bone; *o,* olfactory cartilages; *on,* orbito-nasal foramen; *pa,* anterior ascending process of palato-quadrate; *pg,* pterygoid bone; *pl,* plectrum; *pm,* posterior maxillary process; *pp,* posterior ascending process of palato-quadrate; *pq,* palato-quadrate cartilage; *pt,* pterygoid process of palato-quadrate; *px,* premaxillary bone; *qj,* quadrato-jugal bone; *II,* foramen for optic nerve; *III,* foramen for III cranial nerve; *IV,* foramen for IV cranial nerve. (From Ziegler.)

The remaining portion of the skull which develops from the visceral arches is connected with the jaw, and will be described shortly.

The **infundibulum** and **pituitary body** lie within the **basi-cranial fontanelle,** which is the open space just anterior to the tip of the notochord. From now on, development continues mostly in the posterior portion of the cranium.

Figures 310 and 353 show how the auditory organ is formed by a connective tissue capsule which soon becomes cartilage, while the **mesotic cartilage** grows out posteriorly and laterally from the parachordal plate to unite with the auditory capsule ventrally, both anteriorly and posteriorly.

The **occipital cartilage** is a continuation of the mesotic cartilage which fuses with the auditory capsule, and leaves a small opening through which the IX and X cranial nerve pass. This opening is called the **jugular foramen.**

The **basal plate** is the name given to the floor of the posterior portion of the cranium, which consists of occipital and mesotic cartilages together with the parachordal plate.

The occipital cartilage extends dorsally around the neural cord to form the **foramen magnum.**

The auditory capsule remains open into the cranial cavity internally by a large foramen, but closes externally.

The trabeculae now grow across the basicranial fontanelle so that it becomes entirely closed. This closed portion is the floor of the cranial cavity. The trabeculae then extend laterally and form the lateral walls of the cranial cavity, thus separating the cavity from the orbits.

Cartilages from the trabeculae also extend dorsally across the midline in the anterior region, thus forming a narrow dorsal bridge, leaving a large **supracranial fontanelle** between this bridge and the supraoccipital region.

The internasal septum extends dorsally and becomes the anterior wall of the cranial cavity, while the trabecular cornua remain separate from the olfactory capsules, but connect anteriorly with the suprarostral or labial cartilages. During metamorphosis, however, both labial cartilages and anterior ends of the cornua disappear in front of the olfactory capsules.

True bones form late in the frog, the following being the more important ones which have developed from cartilage:

Exoccipitals, or Lateral Occipitals. These form from the posterior portions of the occipital cartilage and auditory capsule. The occipital condyles themselves as well as the median dorsal and ventral portions of the occipital region remain as cartilage.

Pro-otics. These form from the more anterior portion of the auditory capsules as well as from the basal plate and orbital region.

Ethmoids. These form in the anterior portion of the wall of the orbit. They then unite both above and below so as to form a band around the cranium, often also called the **sphenethmoid** or **orbito-sphenoid.**

Quadrato-jugal. The palato-quadrate cartilage forms bone only in the region of the lower jaw. Then a connection is formed with a membrane bone and these two together form the **quadrato-jugal.** All these bones form before metamorphosis, the ethmoids alone developing some weeks after metamorphosis has taken place.

The Visceral Skeleton. In the mandibular and hyoid arches as well as the three branchial arches, the various skeletal elements **appear as condensations in the mesenchyme,** which soon become cartilaginous.

First, a **short rod** appears in the mandibular arch, transverse to the axis of the embryo.

This divides the dorsal portion into the beginnings of the upper jaw or **palato-quadrate,** and the ventral portion which is the beginning of the lower jaw. The lower jaw element becomes subdivided into **Meckel's cartilage,** which comes to form the true jaw, and the **infra-rostral cartilage.**

The **palato-quadrate** has grown rapidly, as already described, and then fused with the trabeculae.

When the tadpole is about twenty-one millimeters long, the posterior or quadrate portion of this same cartilage connects with the auditory capsule.

With metamorphosis, the mouth enlarges, and this pushes back many of these structures, while the part of the palato-quadrate which lies in the orbital region, softens and disappears to a considerable extent. The anterior connection of palato-quadrate and trabeculae becomes the future **pterygoid** and **palatine** regions. All these changes draw the jaw to the posterior portion of the cranium from its original anterior position.

The infra-rostral cartilages, which have fused together across the midline, now fuse with the Meckelian cartilages to form the apex or **mental portion** of the chin. The fused cartilages are now known as **mento-Meckelian cartilages.** As these ossify, they fuse with the dentary, which is really the chief membrane bone of the lower jaw. There is a small median element between the infra-rostrals which also fuses with them.

The **annulus tympanicus** is the outgrowth from the quadrate cartilage which surrounds the tympanic membrane of the frog. It does not complete its growth until long after metamorphosis.

The **hyoid arch,** like the three branchial arches lying posterior to it, makes its appearance as a pair of rods of dense tissue in the corresponding visceral arches, though not at the same time as the others.

The hyoid cartilage, also called the **ceratohyaal cartilage,** extends dorsad and connects with the palato-quadrate immediately behind where the jaw articulates. Ventrally, it unites with the hyoid cartilage of the opposite side. (Fig. 354.)

The first branchial cartilage also unites in the ventral midline, while the remaining branchial arches do not unite in the midline ventrally, but have their lower anterior ends unite with the one lying immediately anterior to it, and, finally, they connect dorsally in a similar manner.

The **copula,** which is a medial element, then appears in the ventral region of the pharynx between the hyoid and the first branchial, and connects the ventral ends of both these arches.

The **hypo-branchial plate** consists of the lower ends of the first branchials which have become flattened and expanded. The ventral ends of the other three branchials fuse with the hypo-branchial plate.

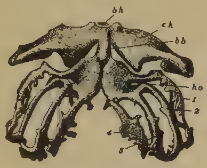


Fig. 354.
Hyoid and branchial arches of a 29 mm. larva of *R. fusca*. Ventral view. *bb*, Basibranchial (first), or copula; *bh*, basihyal; *ch*, ceratohyal; *ho*, hypobranchial plate; 1-4, first to four ceratobranchials. (From Ziegler.)

The **cerato-branchials** are the lateral and middle sections of the branchial cartilages between the visceral pouches which remain separate from one another.

At metamorphosis, when the gill slits close, many changes naturally must take place in the structures just described. For example, the hyoid bar loses its connection with the palato-quadrate, and becomes smaller in diameter, while the copula likewise becomes smaller and a pair of new cartilages develop on each side of it, which then connect the hypo-branchial plate with the hyoid portions. These are the **manubrial cartilages.**

The **hyo-branchial apparatus** of an adult frog is made up of a broad median plate of cartilage which has been formed by the fusion of manubrium, copula, and hypo-branchial plate. The hyoid cartilages remain as slender processes called the **hyoid cornua.** The remaining portions practically disappear.

The membrane bones. In those portions of the cranium where considerable stretching has taken place, such as in the roof of the skull and the lining of the mouth, the substance is thinner than in the cartilaginous portions, and is then called **membrane.**

Membrane is nothing more than stretched-out-cartilage.

The **Parasphenoid.** This is a single median bone, and the first of all bones of the skull to appear, whether cartilaginous or membranous. It forms in the roof of the mouth when the tadpole is about twenty millimeters long. The parasphenoid becomes dagger-shaped and covers the entire basicranial fontanelle.

The **frontals and parietals,** which are paired, appear later and cover the supracranial fontanelle. They later fuse to form the fronto-parietals.

The **nasals** form the roof of the olfactory capsules and the **septo-nasals** or **intra-nasals** appear within the capsules.

The **premaxillae** and **maxillae** are the membranous parts which become the margins of the upper jaw.

The **dentary** and **angular** cartilages surround Meckel's cartilage; the dentary connects with the infra-rostrals of Meckel's cartilage.

The **vomers** are paired, and appear beneath the olfactory capsules.

The **palatines** form across the anterior margins of the orbits.

The **pterygoids** form along the inner faces of the palato-quadrate cartilages.

The **squamosals** form along the outer face of the palato-quadrate cartilages, and ultimately reach back to the auditory capsules. The **quadrato-jugal** is that portion which has developed at the posterior angle of the palato-quadrate cartilage and then fused with the quadrate bone. This is the only one of the membranous bones which cannot be distinguished from the cartilaginous bones of the skull.

CHAPTER XLVI.

MAMMALIAN EMBRYOLOGY

In both the chick and the frog—the two forms we have thus far discussed—the eggs have passed out of the body of the mother. In the frog, the entire embryo developed **after** the egg left the mother, while in the chick where fertilization is internal, development began before the shell was formed, so that an embryo, approximately twenty-four hours old, was already present when the egg was laid.

Now we shall deal with **viviparous animals,** that is, with those which give birth to living young.

It will be understood quite readily that in those cases where living young are brought forth, the development must take place within the body of the mother, but, even in viviparous animals there are subdivisions. One sub-division is made up of such animals as the duckbill, the Australian ant-eater, the Australian kangaroo, and the American opossum. In these animals, known as **Marsupials,** the female bears a pouch in the abdominal region in which the young are placed at a very premature age. In fact, in the opossum, the embryo may be only about eight days of age when it is born for the first time so to speak. The mother then places it within the pouch or **marsupium,** and here the young continue their development until able to lead an independent existence.

In all the higher forms of mammals with which the student is familiar, fertilization is internal, as in the chick, and the embryo passes through a process similar to that of the chick, except that this embryonic process takes place within the mother's body.

There is, however, in viviparous animals no real yolk-supply as in both the chick and the frog egg. Consequently, there must be some kind of an arrangement by which the young not only become attached to the uterus of the mother, but there must also be an arrangement by which a blood-supply can pass from mother to offspring, thus taking the place of the nourishment the yolk furnishes in egg-laying animals.

The mammalian egg, not possessing a yolk, is very small.

The **original development** of egg and sperm, however, is not very dissimilar to that already described for the chick.

Before entering into the study of mammalian embryology proper, it is well, at this point, to understand the terminology usually applied to the life-history of a mammal.

First, the period of **gestation** or true embryonic period. It is during this time that the embryo depends upon its connection with the mother's uterus for nourishment. Gestation extends from the time of the fertilization of the egg to the time of birth.

Second, **parturition**, or the actual time of birth. The condition of the offspring at the time of parturition varies to a considerable extent. Some animals are born with the ability to walk and take reasonable care of themselves within a very short time after birth, while some are quite dependent upon their mother for a long time.

Third, the period of **adolescence**, which is that period of life in the young devoted entirely to growth and development. It extends from birth to sexual maturity.

Fourth, **adult life**, or the period of **sexual maturity**. During this period many physiological changes often take place in the individual entirely aside from those of the reproductive system.

FERTILIZATION

As the egg is thrown out of the **Graafian follicle** (Fig. 355), it passes into the **oviduct (Fallopian tube)** and is carried by the cilia in the oviduct to the uterus. If fertilization takes place, the sperm, which finds its way

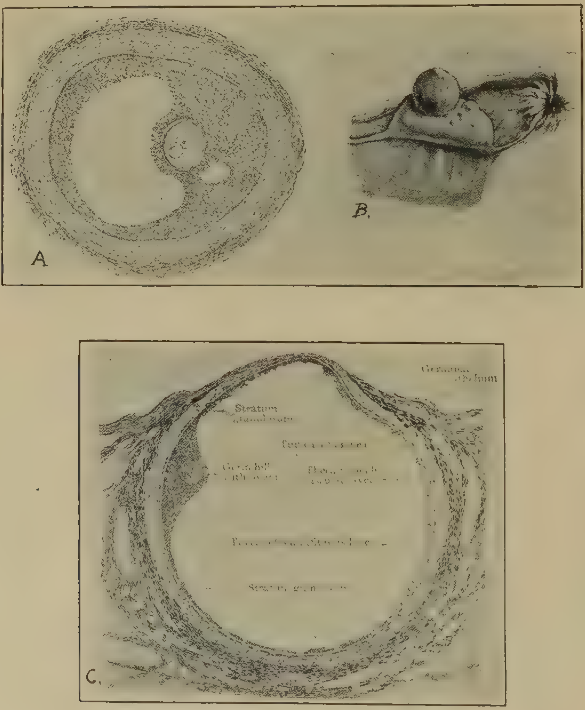


Fig. 355.

A. Section of well-developed Graafian follicle from human embryo (von Herff); the enclosed ovum contains two nuclei. *B*. Ovary with mature Graafian follicle about ready to burst (Ribemont-Dessaignes). *C*. Section of human ovary, showing mature Graafian follicle ready to rupture. *Kollmann's Atlas.*

into the uterus, passes into the oviduct in an opposite direction from that which the egg takes. This causes a meeting of egg and sperm. The length of time it takes the egg to reach the uterus, after ovulation, varies in different species of animals. It may vary from a few hours to several weeks. It is therefore practically impossible to state the exact time when fertilization actually takes place. This is especially true in the human being; but, as soon as the sperm does meet the egg, and fertilization does take place, the embryo begins developing. Consequently by the time the fertilized egg reaches the uterus, it has already passed through, or is just passing through, a stage that is even a little advanced beyond the gastrula stage. There are, in fact, several germ-layers already present at this time.

THE BLASTODERM

As soon as fertilization takes place, the egg divides equally into two cells, these two into four, and so on in the usual way. However, very early, some of the cells divide more rapidly than others, so that there is an overgrowth of those which grow most rapidly. This gives rise to several terms. The more rapidly growing, or **outer layer,** is called the **sub-zonal layer,** while the **central mass** is called the **inner cell mass.**

The sub-zonal layer is only one cell in thickness, so it is easily distinguished from the inner cell mass. Then, too, a cavity forms between the two layers.

The entire structure is now called a **morula** (Fig. 356). As soon as the cavity has definitely formed between the inner cell mass and the sub-zonal layer, the morula is known as a **blastodermic vesicle.** This cavity contains a fluid which is supposed to represent the yolk-mass of the blastula and gastrula in the lower forms.

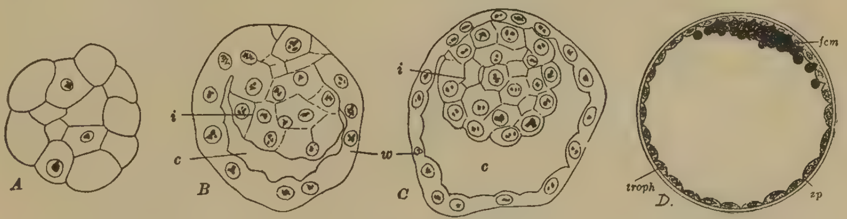


Fig. 356.

Morula and early blastodermic vesicles of the rabbit. The zona radiata and albuminous layer are not shown. *A.* Section through morula stage, forty-seven hours after coitus. *B.* Section through very young vesicle, eighty hours after coitus. Taken from uterus; ordinarily the ova have not reached the uterus at this age. *C.* Section through more advanced vesicle, eighty-three hours after coitus. Taken from uterus. *c,* Cavity of blastodermic vesicle; *i,* inner cell mass; *w,* wall of blastodermic vesicle (subzonal layer, trophoblast). (From Assheton.)

D. Section through the fully formed blastodermic vesicle of the rabbit. *fcm,* Granular cells of the inner cell mass; *troph,* trophoblast cells; *zp,* zona pellucida. (From Quain's Anatomy, after Van Beneden.)

It will be noted from what has just been said that considerable development has already taken place by the time the fertilized egg reaches the uterus. Or, to repeat what was said above, it is as a **blastodermic vesicle that the mammalian egg reaches the uterus after fertilization.**

At this stage, two important points must be considered:

First, **the method of the formation of germ-layers,** and

Second, **the method by which the blastodermic vesicle attaches itself to the uterus of the mother.**

Formation of the Germ-layers.

The inner cell mass spreads out rapidly so as to form an inner lining to the sub-zonal layer. It is this inner lining which is the **entoderm.**

The sub-zonal layer becomes the **ectoderm.**

As there is a tremendous variation in the way germ-layers are formed in mammals, it may be well to think of the following example as a help in understanding some of these variations.

Suppose a group of football players who had already played together in previous years were to come together again. Each would immediately take his place without any preliminary instruction. So, we may think of the embryonic cells in the higher mammals taking a definite place and then developing from there on, rather than passing through all the stages of gastrula formation, and this gastrula then actually indenting to make two layers. That is, we may think of those embryonic cells which are to develop into ectoderm and mesoderm actually taking the proper position to develop into these structures without first becoming a single sheet and then indenting.

This would mean that the undifferentiated cells which are to become ectoderm would arrange themselves on the outer portion, those which are to become entoderm would arrange themselves more inwardly, and those which are to become mesoderm would take their place between these two layers and then all three could begin developing at about the same time and grow simultaneously.

In the lower mammals such as the cat, dog, rabbit, etc., this inner cell mass (entoderm) keeps pace with the sub-zonal layer, so that the original cavity which has formed between the inner cell mass and the sub-zonal layer is now surrounded by an inner layer of entoderm while the outer layer still remains sub-zonal. In the higher forms such as the primates, that is, in man and the higher apes, the inner cell mass does not grow as rapidly as the sub-zonal layer. There is, therefore, a second cavity formed within the inner cell mass of entodermal cells.

It is the remaining portion of the inner cell mass, after the entoderm has thus separated from it, which is the ectoderm. The sub-zonal layer is then called the **trophoblast** (Fig. 356, D). This trophoblast serves as the attachment of the blastodermic vesicle to the walls of the uterus.

We see from what has been said that a true mammalian gastrula (although formed in a different manner from either that of the chick or the frog) has been established with two definite cell or germ-layers.

ATTACHMENT OF THE BLASTODERMIC VESICLE TO THE UTERINE WALL

There are two general ways in which the blastoderm may become attached to the uterus.

The trophoblast or sub-zonal layer may remain as an outer layer around the entire blastoderm, or the developing embryo within the inner cell mass may push through this outer layer and come to lie in close relationship to the uterine wall.

At about the same time that attachment of blastoderm and uterine wall takes place, the **amniotic cavity** is formed (Fig. 357). The trophoblast remains as an outer covering in man, in many primates, and in such animals as the mouse, rats and guinea pig. When the trophoblast remains as the complete outer covering such a condition is known as **entypy,** and it is in animals in which this condition occurs that a definite space is formed between the germ layers and the trophoblast. This cavity is known as the **amniotic cavity.**

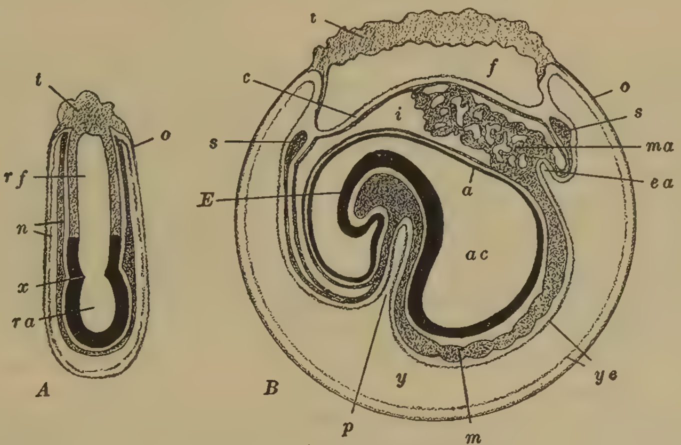


Fig. 357.

Diagrams of the relations of the cavities and layers in the rat, showing the "inversion" of the germ layers. Median sagittal sections. Embryo and amnion, black; ectodermal knob or "träger" in light tone; endoderm and mesoderm in darker tone. *A.* Early stage before the formation of the false amnionic cavity. *B.* Late stage showing false and true amnionic cavities and the interamnionic cavity. *a,* Amnion; *ac,* true amnionic cavity; *c,* chorion; *E,* embryo (anterior end; *ea,* endodermal rudiment of allantois); *f,* false amnionic cavity; *i,* interamnionic cavity; *m,* mesoderm; *ma,* mesoderm of allantois; *n,* endoderm; *o,* trophoblast (ectoderm); *p,* anterior intestinal portal; *ra,* rudiment of true amnionic cavity; *rf,* rudiment of false amnionic cavity; *s,* marginal sinus; *t,* "träger" (ectoderm); *y,* yolk-sac; *ye,* yolk-sac endoderm; *x,* amnionic folds. (After Salenka.)

Sometimes the trophoblast thickens in this particular region and a second or **false amniotic cavity** may develop. Figure 357 will make this clear.

In those cases, however, where the embryo pushes through the trophoblast and comes to lie as a disc upon its surface, the amnion is formed quite similarly to that already described in our study of the chick.

The region in which the embryo develops is known as the **embryonic shield.** The **primitive head-node** lies about in the middle of the embryonic shield. The **primitive streak** and the **primitive grooves** form quite as in the chick, and as there stated, all structures lying anterior to the head-node lie in the head proper.

A definite **notochord** also forms, and the **neurenteric canal** can be seen quite plainly at the posterior limits of the embryonic rudiment.

There are scarcely more than half a dozen human embryos which have ever been seen prior to the time of the formation of the medullary plate. Then, too, none of these were of the same size, so we do not even have a basis for valid comparison, and consequently, we are unable to judge as to whether any of these were normal as to size and form.

Mesoderm is formed in the mammal as it is in the chick, each mesodermal somite dividing into a somatic and a splanchnic layer. A layer of entoderm joins with the splanchnic mesoderm to form the yolk-sac, although no yolk is present. The trophoblast joins with the somatic mesoderm to form the **chorion.**

Here we may note that the term "ovum" is used in mammalian development to designate any early stage in the embryo, even to the inclusion of the entire blastodermic vesicle. The term "embryo" in man is given the embryo only **during the first two months of its existence,** thereafter (that is, when the face and body are quite well formed) it is known as a "foetus."

The smallest human embryo yet seen was 1.54 mm. in length, while the entire blastoderm was about 1 cm. in diameter.

IMPLANTATION

There are three methods by which the blastoderm attaches itself to the walls of the uterus.

First, by what is called **central implantation.** This occurs in the ungulates and carnivores as well as in the lower primates and in some rodents, such as the rabbit. In these the blastoderm becomes superficially attached to the uterine wall, and, consequently, projects freely into the lumen of the uterus.

Second, **eccentric implantation.** This type is found in the mouse and in some insectivora. In these forms the blastodermic vesicle lies in a furrow or groove in the uterine wall. This groove is then closed up so that the vesicle comes to lie in the walls of the uterus.

Third, **Interstitial implantation.** In this type the blastodermic vesicle actually burrows its way into the mucous membrane lining of the uterus.

It is this third type which occurs in man and in some of the rodents such as the guinea pig and the gopher.

The trophoblast, in the region where it is to meet with the uterine wall, has become highly specialized physiologically in the eccentric and interstitial types of implantation. Its cells form a layer of considerable thickness and it is then called a **trophoderm** (Fig. 358). These cells are supposed to dissolve or digest the uterine mucosa so as to permit a definite implantation and also, probably, to digest some of the mucosa as food for the growing embryo.

The blastoderm attaches itself to the uterine wall between the two oviducts, and it is in the region of implantation that the maternal tissues come into contact with the embryo. We must, therefore, look for the beginnings of the **placenta** in this region.

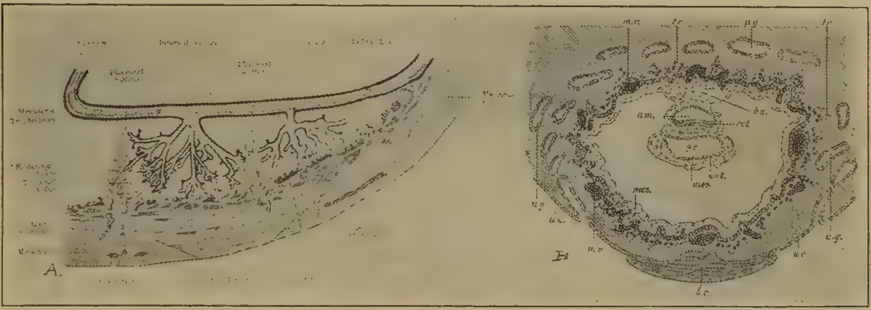


Fig. 358.

A. Diagrammatic section of placenta. (After Strahl, Bonnet.)
B. Section through an embryo of 1 mm. embedded in the uterine mucosa (semidiagrammatic after Peters). *Am.*, amniotic cavity; *b.c.*, blood-clot; *b.s.*, body-stalk; *ect.*, embryonic ectoderm; *ent.*, entoderm; *mes.*, mesoderm; *m.v.*, maternal vessels; *tr.*, trophoderm; *u. e.*, uterine epithelium; *u.g.*, uterine glands; *y.s.*, yolk-sac.

In fact, it is the trophoderm which later becomes vascularized from the mesoderm of the chorion or allantois, to act as the chief absorptive surface through which, and by which, material from the maternal tissues and blood is taken to the embryo.

THE EMBRYONIC MEMBRANES

It will be remembered that in the chick embryo, the amnion has as one of its functions the protection of the embryo from drying and from becoming deformed by the outer shell pressing against it. The chick's yolk-sac contains a large quantity of food-substance which the developing embryo uses, and the allantois serves as a respiratory and (partially) as an excretory organ. In the chick the serosa or chorion was of little importance.

In the mammal it is the amnion which is of secondary importance. The yolk-sac has no yolk in it and in so far as we know has little functional value. The allantois has but little respiratory and excretory significance. Its work is practically to bring the embryo in relation to its food supply. It is the **chorion** which becomes the principal organ by which nutritive material and excreted substances between maternal and embryonic circulations take place.

It is this connection between mother and embryo which brings about the formation of what is called the **placenta.** All mammals which develop a placenta—that is, all mammals except those which lay eggs—are known as **placentals.**

THE PLACENTA

The detailed development of mammals must be left to much larger volumes than this one, especially as there are so many variations occurring even in quite similar groups of animals.

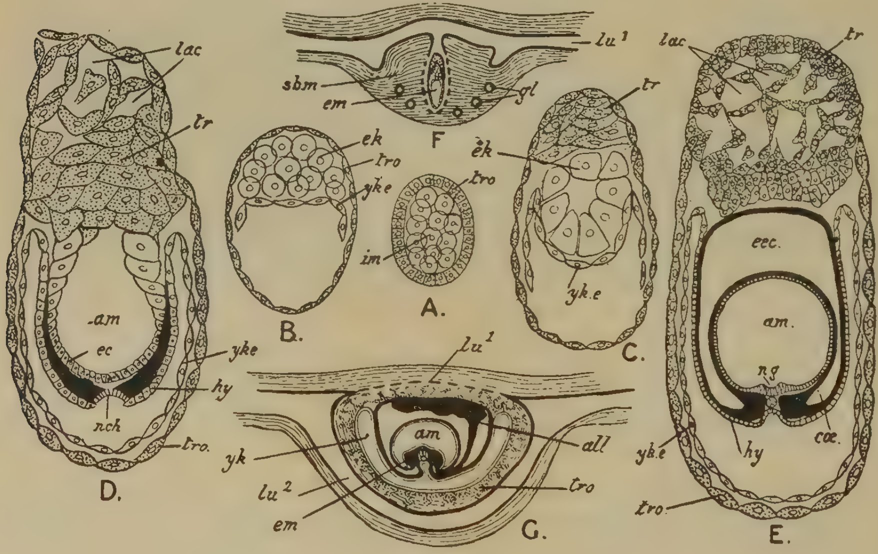


Fig. 359.

Diagrams illustrating the development of the blastocyst and formation of the placenta in Mammalia. *A*, a blastocyst at the end of segmentation; *B*, an older blastocyst, in which a cavity has appeared to one side of the inner mass of cells; *C*, a later stage, showing the formation of the träger and growth of the yolk epithelium round the yolk cavity; *D*, formation of lacunæ in the träger and commencement of the embryo; *E*, further development of the träger, the mesoblast has split and the amnion and extra-embryonic cœlom are formed; *F*, longitudinal section of uterus, showing the position of the embryo in a pit in the uterine wall. *G*, longitudinal section of a later stage, showing the obliteration of the old lumen and formation of a new lumen in the uterus. *all*, allantois; *am*, amniotic cavity; *cœ*, embryonic cœlom; *ec*, epiblast; *eec*, extra embryonic cœlom; *ek*, embryonic knob; *em*, embryo; *gl*, uterine glands; *hy*, hypoblast; *im*, inner mass of cells; *lac*, lacunæ in träger; *lu*^{1}, original lumen of uterus; *lu*^{2}, secondary lumen of uterus; *nch*, notochord; *ng*, neural groove; *sbm*, thickened sub-mucous layer of uterus; *tr*, träger; *tro*, trophoblast; *yk*, yolk-sac; *yk.e*, yolk epithelium. In all the figures the trophoblast is shaded with dots, and the embryonic mesoblast is represented in black. (After Bourne.)

But as the student must know the placental animals in order to make the most of his study in Comparative Anatomy, it is essential that he at least obtain a clear and accurate understanding of the two principal types of placental formation.

In the first place, the placenta may be defined as consisting of **all structures affecting nutritive, respiratory, and excretory interchanges between the embryo and its mother** in viviparous animals. It is evident, then, that the placenta must form in the region where the trophoblast comes in contact with the uterine mucosa, and that the trophoderm itself plus the vascularization in the yolk-sac, allantois, or chorion, will be the elements from which the placenta is developed. (Figs. 358, 359.)

At this stage the student must review the chapter on the development of the extra-embryonic membranes in the chick.

The rabbit is often used as an example of a form of mammalian embryology which can be contrasted with the embryological development of the chick. In the rabbit the extra-embryonic membranes develop quite like those in the chick, except that the point of fusion of these membranes consists of only a small knot, whereas in the chick this fusion takes the form of an elongated seam. In both rabbit and chick the tail-fold grows more rapidly than the head-fold.

In man, where entypy takes place (that is, where the trophoblast remains continuous about the entire blastoderm), the extra-embryonic membranes do not grow as in the rabbit and chick, but by **a splitting of the ectoderm to form the beginning of the amniotic cavity.**

The forming of the extra-embryonic membranes in man quite naturally causes the embryo to remain connected with the blastodermic wall by a **body-stalk** (Fig. 358, B). The separating of the ectoderm immediately above the embryo to form the amniotic cavity causes the **embryo** to form the **floor** of this cavity, while the trophoblast forms the **roof.** The sides, or **walls,** of the cavity meet the embryo at the edges of the embryonic shield.

But, whether the amniotic cavity is formed as in the rabbit or as in man, the walls of the cavity extend ventrally until they surround the umbilicus.

The yolk-sac and the yolk-stalk, as well as the allantois, although quite small in man, are pushed into this **body-stalk** or **umbilical-stalk.** The amniotic cavity grows large in man and contains from one-half to one liter of **liquor amnii.**

THE YOLK-SAC

The open space on the interior of the mammalian blastodermic vesicle is supposed to represent the yolk-sac (Fig. 359, G) of such animals as the chick and the frog; and, as this open space is relatively very large, the yolk-sac occupies the main portion of the early mammalian blastodermic vesicle. The cavity of the vesicle opens into the mid-gut region by the broad yolk-stalk just as with the chick. Its wall is separated from the chorion by the extra-embryonic **coelom**—also called the **exocoelom.** (Fig. 359, E.)

The amnion and chorion are formed from somatopleure, while the yolk-sac is formed from splanchnopleure.

The blood vessels and the sinus terminalis arise in the yolk-sac of the rabbit just as they did in the chick.

In the higher primates, including man, the yolk-sac never fills the entire blastodermic vesicle and is very slow to grow. In fact, during the first month it has a diameter about the length of the embryo, and after increasing this diameter to a little over a centimeter, it decreases in size. The yolk-stalk is formed, however, and elongates considerably to enter the proximal end of the umbilical cord.

The amniotic membrane now expands and pushes against the exocoelom until that is eliminated and the yolk-sac disappears in the placental region. The yolk-stalk itself becomes a solid cord during the second month. However, the proximal end sometimes remains open. In such a case it appears as a diverticulum from the intestine and is called **Meckel's diverticulum.**

THE ALLANTOIS

This structure also varies in size to a considerable extent, from filling the entire exocoelom as in the lower primates such as the Lemurs, to occupying but a small portion of the umbilical cord as in man and the higher primates (Fig. 359, G).

The early development of the allantois in the mammals is quite similar to that in the chick, but its later development is varied, the variation being ascribed to the changed conditions brought about by the formation of placental structures.

The later history of the allantois is limited to the placental structures **only.** In the rabbit the allantois extends into the exocoelom and comes in direct contact with the chorion in the region where chorion and uterus unite. It thus lies in the direct pathway of connection between mother and offspring. Blood vessels now develop in the allantoic mesoderm to form the umbilical arteries and the umbilical veins, and it is through these allantoic blood vessels that the **embryonic circulation** is related to the **placental circulation.**

In man the development is quite different; for, here there is nothing which interrupts the connection of chorion with the maternal tissues. The way in which the body-stalk develops in man has been described already. This is often said to be equivalent to a modified allantoic stalk. There is, therefore, in man, **no true allantois as a free vesicle.** Only a small tubular outgrowth from the entodermal lining of the yolk-sac can be seen, and this outgrowth, in turn, is not distinguishable from the hind-gut. It extends into the body-stalk. As the embryo grows, and the body-stalk extends, the allantoic stalk extends further along in the body-stalk as well, and so remains during foetal life (Fig. 360).

As the ventral body-walls of the embryo are formed and approach each other, the proximal end of the allantoic stalk becomes the **urinary bladder** and the beginning of the **urogenital sinus.** From the bladder region to the body-wall it is reduced as a mere solid strand of connective tissue known as the **urachus.**

Vascularization is quite alike in the various mammalian forms.

The development of the placenta depends upon the manner and type of implantation, which in turn causes different relationships between the growing embryo and the maternal tissues.

THE DECIDUAL MEMBRANES

We have been describing the **embryonic placenta.** Now we shall describe the **maternal placenta.** There is a change which takes place in the lining of the uterine walls when the trophoderm unites with the uterus. The uterine lining which bulges out into the uterine cavity to cover the blastoderm is called the **decidua capsularis** (formerly, **decidua reflexa),** while the uterine lining at the point where blastoderm and uterus unite is called the **decidua basalis** or **decidua serotina,** the remaining portion of the lining being known as the **decidua vera** (Fig. 361).

The chorion is at first composed of an inner mesodermal layer and an outer epithelial layer (this latter being called the **trophectoderm).** From the trophectoderm there develops an outer **syncytial layer** which is called the **trophoderm.** It is this trophoderm which invades the maternal tissues. Large **lacunae of blood** are formed in the maternal tissues by the syncytial tissue directly, or by the rupture of the blood vessels which are under great pressure in this region.

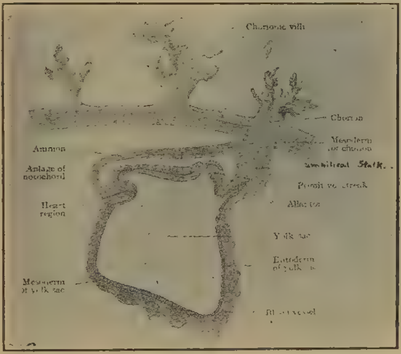


Fig. 360.
Medial section of early human embryo. (After von Spee, Kollmann.)

The trophoderm then thickens at intervals and forms little villi or finger-like projections, and the chorionic mesoderm grows out into these villi so that there is a branching of the **primary villi** into **secondary villi** or **true villi** (Fig. 358)).

In the meantime the blood lacunae run together and surround and bathe the villi, while the trophoderm, which began as a spongy network, is now a continuous layer covering the entire outer surfaces of the villi and chorion.

Branches of the umbilical vessels develop in the mesoderm of the chorion and villi. This means that there are now two layers of epithelium covering the mesodermal core of all the villi, and that it is in these villi that the chorionic circulation of the embryo is established.

The blood vessels of the uterus open into the little blood-lacunae, which is another way of saying that the syncytial trophoderm which covers the villi is bathed in maternal blood. This is where the nourishment of the embryo takes place. **The maternal blood itself does not pass into the developing embryo.**

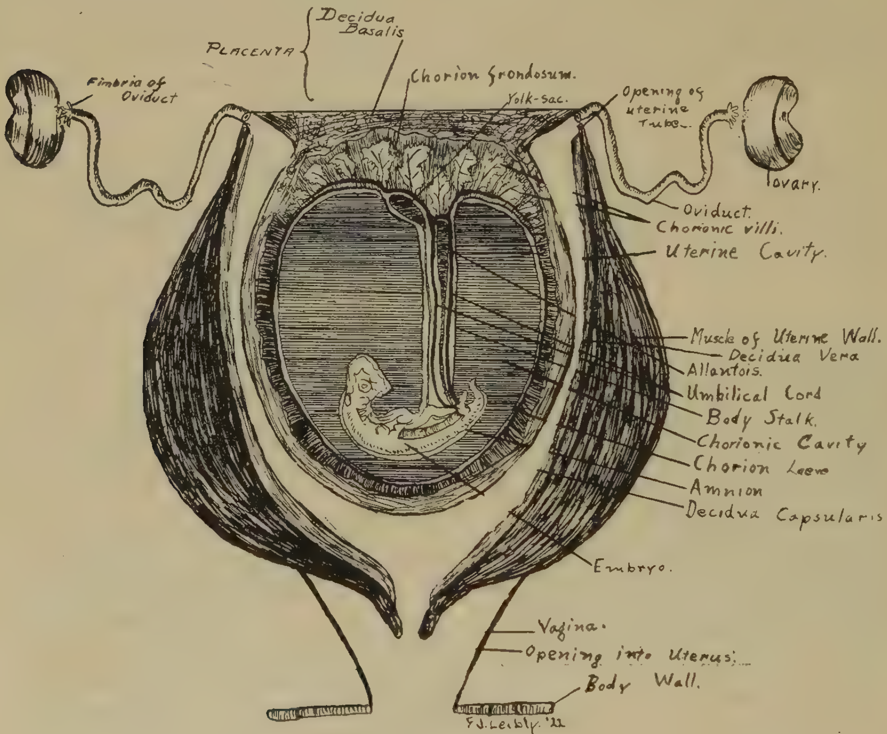


Fig. 361.

Diagram to show relationship of mammalian embryo and maternal membranes.

At first the villi cover the entire surface of the chorion, but in man, after a few weeks, the villi located away from the point of attachment begin to degenerate and finally leave that portion smooth. This smooth region is called the **chorion laeve,** while the attached portion which retains the villi is known as the **chorion frondosum** (Fig. 362). It is the chorion frondosum, together with the decidua basalis, which constitutes the **placenta.** And it is the chorion frondosum to which the embryo is attached by the body-stalk which later comes to be called the **umbilical-stalk** or **umbilical cord.**

The decidua basalis forms what is called the **maternal placenta** and the chorion frondosum the **foetal placenta**.

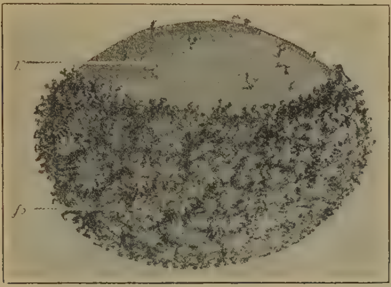


Fig. 362.

Human Embryo. Age seven weeks. (From Kollmann.) *cf*, chorion frondosum. *cl*, chorion læve.

The decidual membranes and their attachments form the **afterbirth**. This afterbirth consists of amnion, chorion, decidua vera, placenta, and a part of the decidua basalis.

THE UMBILICAL CORD

As the body-stalk becomes longer and longer, finally reaching a length of some fifty centimeters, there must be some circulatory connection between the embryo and the chorion frondosum. This connection is brought about by the development of four blood vessels, two veins and two arteries, known as the **umbilical vessels** or **allantoic vessels** (Fig. 363). The two veins push their way into the embryo to open into the heart. The arteries likewise grow in the same direction as do the veins, but connect with the dorsal aorta. Their distal ends extend

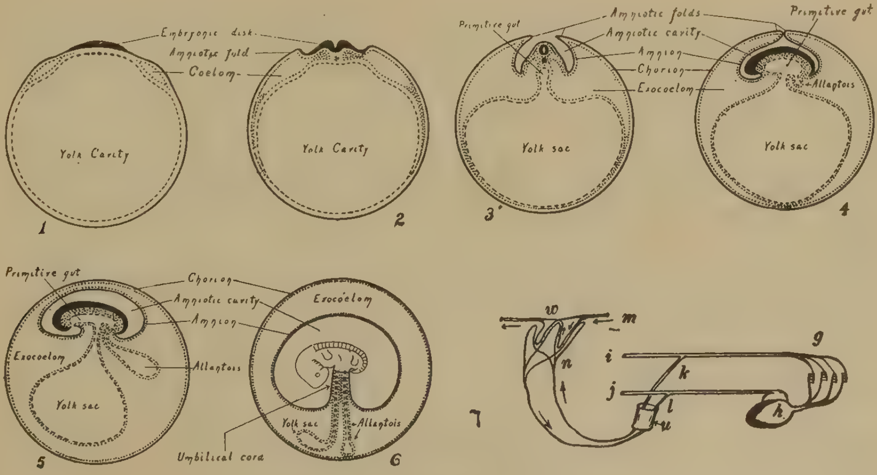


Fig. 363.

1 to 6, Diagrams representing six stages in the development of the foetal membranes in a mammal.

The ectoderm is indicated by solid black lines; the entoderm by broken lines; the mesoderm by dotted lines and areas. (After Kölliker.)

7, Diagram of nurture of young through embryonic membranes. *g*, gill circulation of embryo; *h*, heart; *i*, dorsal aorta; *j*, postcava; *k*, allantoic artery; *l*, allantoic vein; *m*, indicating the course of the blood of the mother, parallel to *n*; *n*, that of the embryo; *w*, wall of uterus. (After Needham.)

through the body-stalk into the villi to connect with the vascularization there established.

The two veins later fuse, so that a cross section of a mature umbilical cord (Fig. 364), shows two arteries and a single large vein.

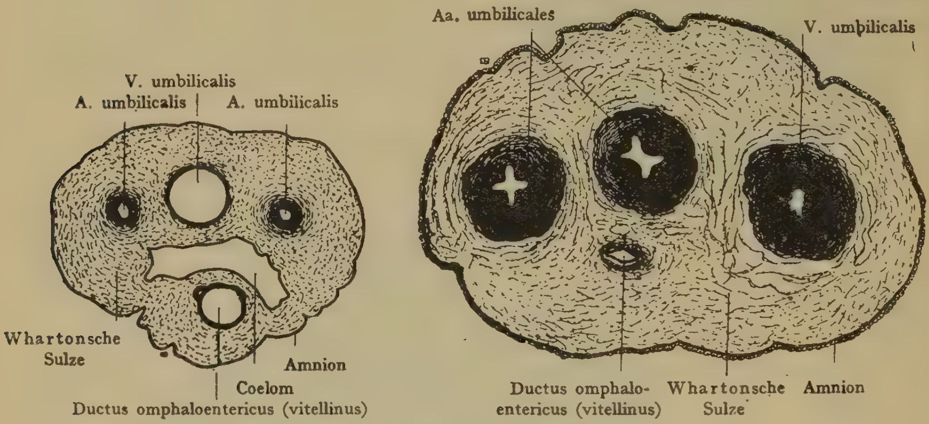


Fig. 364.

I, Umbilical cord of human embryo at three months.
II, Same at birth. (After Corning.)

In addition to the umbilical vessels just mentioned, the yolk-stalk (in the early stages only), and the allantoic stalk can be seen in cross sections of the cord while the cord itself is filled with a mesenchymal, mucous-like substance called **Wharton's jelly.**

The cord is twisted and is attached to the **umbilicus** or **navel** of the foetus and to the placenta. The outer covering of the umbilical cord is a layer of ectoderm which is continuous with that of the amnion of the embryo.

The following table shows the relative increase in size and weight of the human embryo and foetus throughout the period of gestation:

		Length	
	Weight	C. H.	C. R.
Ovum (estimated)	0.000004 grm.	....	....
23 days	0.04	2.5 mm.	2.5 mm.
56 days	3.0	30.0	25.0
84 days	36.0	98.0	68.0
112 days	120.0	180.0	121.0
140 days	330.0	250.0	167.0
168 days	600.0	315.0	210.0
196 days	1000.0	371.0	245.0
224 days	1500.0	425.0	284.0
252 days	2200.0	470.0	316.0
270 days	....	500.0	336.0
280 days	3200.0	....	....

If the student has thoroughly mastered the subject matter of this semester's work in embryology he will not only be able to understand how a normal embryo develops, but he will also know how and why many and varying types of abnormal development occur by either mechanical or chemical injury of some kind, which injury may cause any portion of the embryo to stop growing, while other parts continue in the usual manner. Monstrosities of many kinds may thus be formed, and even in apparently normal individuals it is by no means rare for the surgeon to find individual internal organs underdeveloped or overdeveloped. All such deviations from the normal are of the utmost importance to the medical man, and it is only through a study of embryology that they are made understandable.

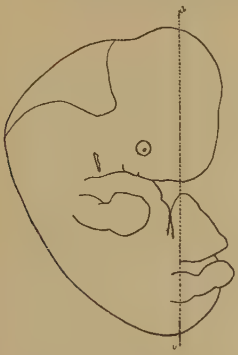


Fig. 365.

Figure to illustrate the "vertex-breech" method of measuring human embryos. *a-b*, vertex-breech length of the embryo.

Part III

Comparative Anatomy

CHAPTER XLVII

INTRODUCTION TO COMPARATIVE ANATOMY

In the study of Comparative Anatomy a method somewhat different from our study up to this moment must be brought into play.

In the forepart of this book the frog was studied as a **type-form of vertebrates,** and the earth-worm as a **type-form of annelids,** as well as of **coelomates,** and then, **after** each such type-form had been studied, it was compared with other forms likewise studied in the laboratory.

Now we are to take an **entire system in each of the leading groups of vertebrates and compare system by system,** always **reviewing the development** of the particular system studied, and comparing such development with the development of the respective systems in both frog and chick, as shown in **part three** (embryology) of this book.

Three distinct points of view must be kept in mind in comparative anatomy:

Structure (both gross and microscopic).

Development (embryology).

Comparison of organ systems.

Just as in any account of man's history we attempt to study those races which we now consider as living under primitive conditions, believing that they will throw some light upon the problems that our ancestors had to overcome in order to bring about our present state of civilization, so, in comparative anatomy we attempt to study the so-called lower-animal life in order that this may throw light upon the development of our own bodies. This may be brought home the better by remembering that all higher forms of life practically possess all organs and systems of organs that the lower forms possess, **plus an additional something.** This does not prove by any means that any of the higher systems must have necessarily come from the lower. All it does mean is that all forms of animals which walk on the earth must have much that is similar. For instance, legs that are used for the same purpose in all animals must have muscles that will function alike; because, regardless of what position we systematically assign these animals, they, by virtue of the fact that they must walk, must necessarily have leg muscles, and having these, there must be a supporting structure for such muscles, so that the skeletal systems of walking animals will be closely akin.

Comparative Anatomy proper, then, will consist of a comparison of the organ systems of four great groups of vertebrates. The classic examples used for such comparison are:

The **dogfish** as an example of a group of living organisms whose skeletal tissues are largely cartilaginous.

The **turtle** as an example of the **reptilia.**

The **cat** as an example of the **mammalia.**

The **frog** is the classic example of the **amphibian.** This animal has already been studied in the early part of the course, but must be kept in mind so as to be compared with the above three types.

It is usual to exclude the aves, because reptile and bird have so many structural similarities that the study of one suffices for that of the other. In fact the single word **Sauropsida** has come into common biological usage as meaning both reptiles and birds.

It is necessary first for us to have some conception of what is meant by the phylum **Chordata** and to appreciate that there are intermediate types between invertebrates and vertebrates. Such intermediate types are known as **pro-chordata.** The **pro-chordata** and the **vertebrata** together form what Zoologists call the pyhlum **Chordata.**

The vertebrates possess a spinal or vertebral column which consists of a great number of similar portions called **vertebrae** arranged in a longitudinal series. In the early embryo of all vertebrata there appears a rod-like **notochord.** This probably serves as a sort of stiffening to the animal and in this respect only is it similar to the spinal column proper. It is neither cartilage nor bone, and probably develops from the **entoderm or mesoderm.** As the **spinal cord develops from the ectoderm,** and the **bones** of the spinal column **from the mesoderm,** it will be seen that neither of these three just-mentioned portions are alike in either origin, function, or position.

In all vertebrates the main nerve cord lies on the **dorsal side** while in **invertebrates it lies on the ventral side.**

There are certain groups of animals which possess no spinal column, yet, during the embryonic period have a notochord, a dorsal nerve cord, and a gill-slit apparatus (Figs. 313, 314, 315, 316). The classic examples of these forms are **Amphioxus, Balanoglossus,** and the **tunicate or sea squirt,** all of which are comparatively small in size and live in the sea. These forms are grouped together under the name of **pro-chordata.** Professor Patton of Dartmouth College has described a scorpion in which he is sure he has found a notochord. If he is correct it will be seen that no classification of this kind is absolute, in that invertebrates of very early geologic times may have possessed such an embryological structure.

CHAPTER XLVIII

CLASSIFICATION OF FISHES, AMPHIBIANS, REPTILES, AND MAMMALS.

Unless this chapter is mastered, there can be no understanding of the textual matter which follows, as the scientific terms there used are all based on what this chapter contains.

CHORDATA

The **Chordata** possess a notochord at sometime during their life's history (the notochord lying between the nervous system and the alimentary tract), a hollow central nervous system lying entirely on one side of the digestive canal, and pharyngeal slits extending from the pharynx to the exterior.

The Chordata are divided into four sub-phyla, all of which develop a notochord during their embryonic period, though all do not later develop a bony vertebral column.

The sub-divisions of the Chordata (Figs. 313, 314, 315, 316) are as follows:

Sub-Phylum I. Cephalochordata (Adelochorda, Fig. 312).

The notochord runs only up to the head proper in most chordates, but in the **Cephalochordata,** of which **Amphioxus** is the classic example, the notochord extends to the very anterior end of the body. **Amphioxus** is fish-like in form and is used as an example of the most primitive form of the chordates. It will be remembered that there was reference made to the simplicity of the embryology of **Amphioxus** in Part III of this book.

Amphioxus has no skull or vertebral column. The pharyngeal slits are quite numerous. The true scientific name of **Amphioxus** is **Branchiostoma.** In popular language it is often called **lancelet,** on account of its sharp, lance-like appearance.

Sub-Phylum II. Urochordata (Tunicates, Figs. 312, 313).

This group possesses a notochord only in the caudal region. The young are tadpole-like, and there is a metamorphosis converting the tadpole into a sac-like structure.

Order I. Larvacea (Appendicularia), free-swimming forms with permanent tail.

Order II. Ascidiacea (Tunicates or Sea-Squirts), fixed forms without tail in the adult.

Order III. Thaliacea (Salpians), free-swimming forms without tail in the adult.

The neurenteric canal is permanent.

Sub-Phylum III. Hemichordata (Fig. 314).

A rather doubtful form. There is a projection from the mid-dorsal region of the digestive canal which looks somewhat similar to a notochord. These animals have a collar and a proboscis.

Order I. Enteropneusta, which include worm-like forms such as **Balanoglossus.**

Order II. Pterobranchiata, sessile; tube-dwelling forms such as **Cephalodiscus,** and **Rhabdopleura.**

Order III. Phoronidia, tubicolous forms such as **Phoronis** (Fig. 199).

Sub-Phylum IV. Vertebrata (Craniata).

1. The vertebrates show their segmentation in the adult form only on the interior of the body, as for example, the metameric arrangement of myotomes, sclerotomes, etc.
2. A cuticular skeleton is absent, but there may be cornifications of the epithelium, or ossifications in the dermal regions, such as the scales of fishes, etc.
3. An axial skeleton is present consisting of skull and vertebral column.
4. There are two kinds of appendages supported by the axial skeleton, namely, the unpaired fins (which occur only in fishes and Amphibia), and the paired appendages (anterior and posterior), which are usually present.
5. The central nervous system is dorsal in position. The brain itself consists of five parts: the cerebrum, "twixt-brain," mid-brain, cerebellum, and medulla oblongata.
6. Of the sensory organs, the eyes and ears are the most highly developed.
7. The respiratory organs arise from the entoderm of the pharynx. Pharyngeal slits are present in the embryo. In terrestrial animals these pharyngeal slits are later functionally replaced by lungs which develop from the hinder portion of the pharynx.
8. The heart lies ventrally in the pericardium. In gill-breathing species it contains only venous blood, but in lung-breathing animals it is divided into venous and arterial halves. The circulation is closed.
9. The sexes are usually separate, while in most species the excretory (nephridial) system forms the ducts for the reproductive (genital) system.
10. Reproduction is strictly sexual.

The classes of Vertebrata are as follows:

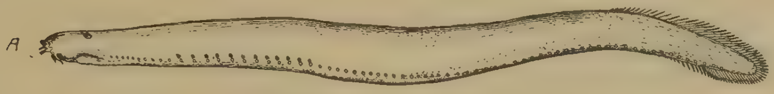
Class I. Cyclostomata (Fig. 366).

These are the round-mouthed eels without a lower jaw. Examples are the lampreys and hagfishes. It is in this group that we find the only vertebrate parasites.

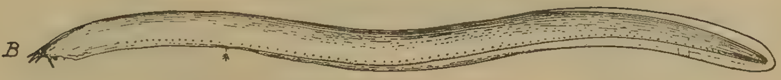
There is a primitive skull, but no true vertebrae (only bony arches). Paired fins, true scales, and teeth are lacking. The gill-pouches are saccular and the nose is unpaired.

Sub-Class I. Myxinoidea (Fig. 366).

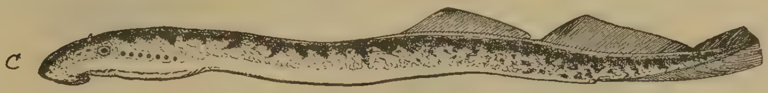
These are the "hag-fishes" or "borers" which give off a slimy, mucous jelly when captured . It is from this fact they receive their name of **Myxinoidea.**



Bdellostoma dombeyi (Pacific hagfish)



Myxine glutinosa (Atlantic hagfish)



Petromyzon marinus (sea lamprey)

Fig. 366.

Cyclostomes. The light openings along the sides are mucous canals, the dark ones are branchial openings.

Sub-Class II. Petromyzontia (Fig. 366).

These are the lampreys, which live in both salt and fresh water. The **myxinoids** attack principally dead and disabled fishes, but the **petromyzons** attack decidedly active fish much larger than themselves, attaching themselves to their host and making great inroads with their rasping tongues.

Class 2. Pisces (Gnathostomata). All fish having true lower jaws.

Fishes are distinguished from the **Cyclostomes** not only by having true lower jaws but also by having a vertebral column **(amphicoele vertebrae,** Fig. 404), by having scales, paired pectoral and pelvic fins, and paired nostrils. They breathe by gills and have a heart with venous blood therein only, although the heart has auricle, ventricle, sinus venosus, and some have a conus arteriosus.

Sub-Class I. Elasmobranchii.

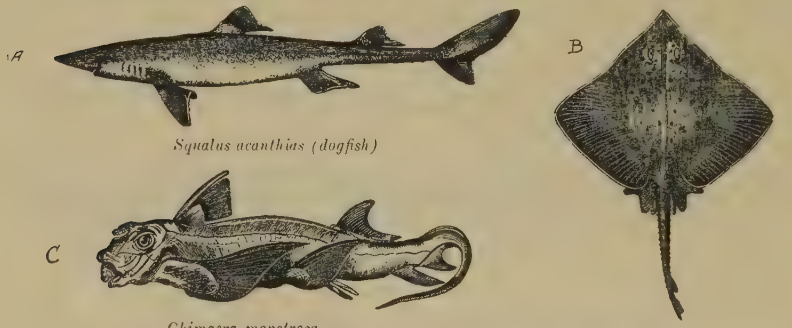
These are the sharks and their near relatives. They have a cartilaginous skeleton, usually a heterocercal tail, placoid scales (thornlike), but in **Mustelus** (the dog-shark, which is used in the laboratory), pointed, overlapping scales. There are five to seven slit-like gill-openings on each side. The eggs are few and hatched within a sac inside the body. The **skates** also belong to this group. They are merely flattened out sharks.

There are various extinct orders and sub-orders of elasmobranchs, but we shall deal only with two orders and two sub-orders.

Order, Plagiostomi.

Sub-Order I. Selachii (12 living and 3 extinct families of sharks and dog-fishes, Fig. 367).

Sub-Order II. Batoidei (Saw-fishes, skates, rays and torpedoes, 7 families, Fig. 367).



Squalus acanthias (dogfish)

Chimaera monstrosa

Raia erinacea (common skate)

Fig. 367. Elasmobranchii.

(A, after Goode; C, after Claus.)

Order Holocephali (Chimaera, Fig. 367, 1 living and 3 extinct families).

The Holocephali are very grotesque looking animals and are of great antiquity. There are peculiar grinding plates in the mouth instead of teeth.

Sub-Class II. Teleostomi. (The true bony fishes).

Skeleton partly or entirely bony, a single gill-opening on each side leading to gill-arches on which there are gill filaments. There is also a swim-bladder, although this may disappear with age.

In the higher forms where the skeleton is entirely ossified, the pelvic girdle approaches the pectoral one, so that the pelvic fins may be directly beneath the pectoral fins. It is this approach of the girdles and fins which is used in classifying fish, because this is supposed to show different degrees of specialization.

The position of the fins in the higher fishes is supposed to furnish evidence to show that amphibians and higher fishes are not closely related.

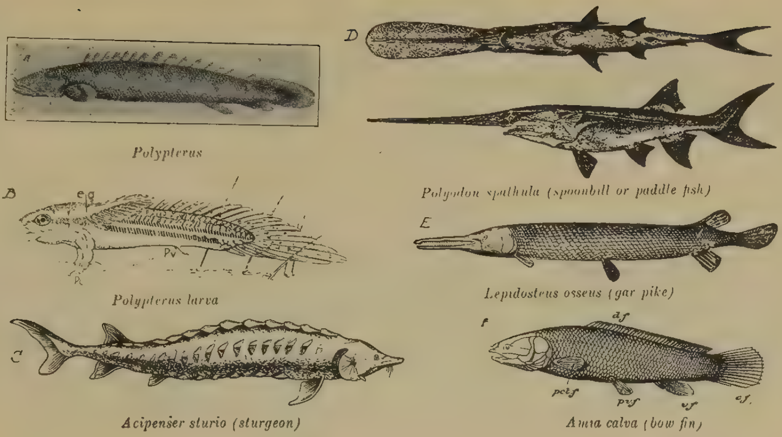
Order I. Crossopterygii.

Sub-Order I. Osteolepida. (4 extinct families).

Sub-Order II. Cladista. Polypterus and **Calamichthys** are the usual examples. (Fig. 368).

Order II. Chondrostei (5 extinct and 2 living families).

These include the paddle-fishes and sturgeons (Fig. 368).



Polypterus

Polyodon spathula (spoonbill or paddle fish)

Polypterus larva

Lepidosteus osseus (gar pike)

Acipenser sturio (sturgeon)

Amia calva (bow fin)

Fig. 368. Ganoids.

In *B*, *e.g.*, Large external gill of the hyoid arch; *Pc.*, pectoral fins; *Pv.*, pelvic fins. The larva is drawn in a very characteristic attitude.

In *C* note the elongated snout, the barbules bounding the ventral mouth, the operculum covering the gills, the rows of bony scutes, the markedly heterocercal tail.

D, Ventral and side view.

F, *Amia calva* (Bow fin). *c.f.*, caudal fin; *d.f.*, dorsal fin; *pct.f.*, pectoral fin; *pv.f.*, pelvic fin; *v.f.*, ventral fin. (B, after Budgett; D, after Goode; E, after Tenney; F, after Günther.)

Order III.* **Holostei** (6 extinct and 2 living families).

These include the bow-fins and gar-pikes. (Fig. 368).

Order IV. Teleostei.

Sub-Order I. Malacopterygii (21 families).

These include tarpons, herring, salmon, etc. (Fig. 369).

Sub-Order II. Ostariophysi (6 families).

These include carp, tench, cat-fishes, etc. (Fig. 369).

Sub-Order III. Symbranchii (2 families).

A small group of eel-like fishes having characteristics of both **Ostariophysi** and **Apodes.**

Sub-Order IV. Apodes (5 families).

These are the eels. (Fig. 369).

Sub-Order V. Haplomi (14 families).

These are the pickerel, killifishes (mud-minnows), etc.

Sub-Order VI. Heteromi (5 families).

These are the **Fierasfer,** etc. (Fig. 370).

Sub-Order VII. Catosteomi (11 families).

These are the stickle-backs, pipe-fishes, sea-horses, etc. (Fig. 370).

Sub-Order VIII. Percesoces (Flying fishes) (12 families).

These include the **Belone,** sand-eels, rag-fishes, etc. (Fig. 370).

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*The student will meet with the term "Ganoid" in his reading. This merely refers to a *shiny scale*. In the United States the gar-pike (*Lepidosteus*) found in the Mississippi Valley, is commonly mentioned, although older writers made a distinct grouping of Ganoids, consisting of Orders I, II and III, using the African *Polypterus* as the classic example. In *Lepidosteus*, Ganoid scales have a sort of peg and socket arrangement.

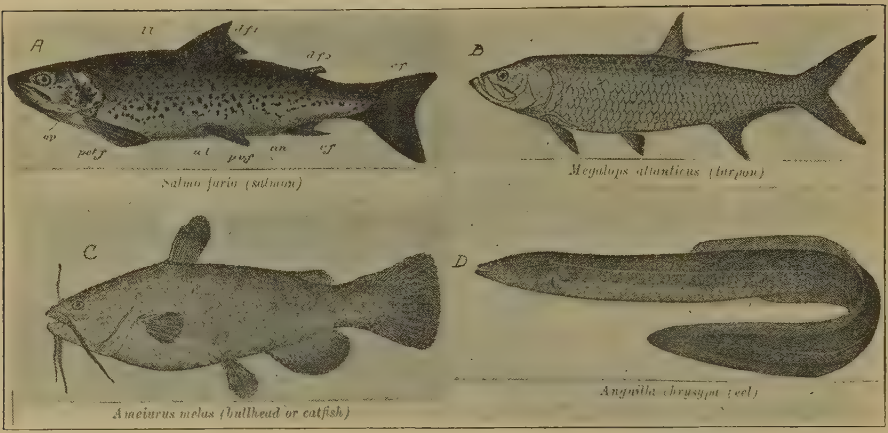
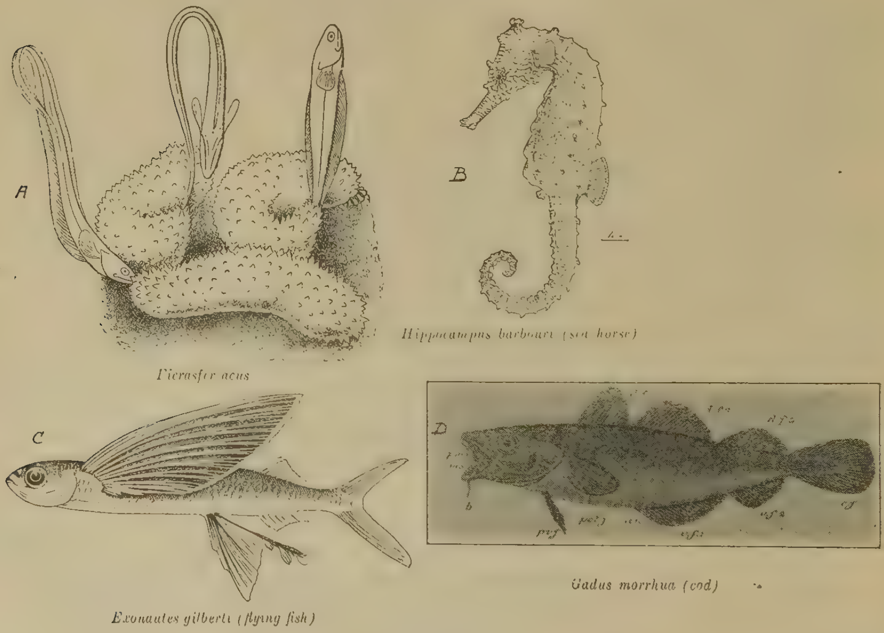


Fig. 369. Teleostei.

A, Brook Trout, a sub-genus of the Salmon family, *a.l.*, adipose lobe of pelvic fin; *an.*, anus; *c.f.*, caudal fin; *d. f. 1*, first dorsal fin; *d. f. 2*, second dorsal or adipose fin; *l.l.*, lateral line; *op.*, operculum; *pct.f.*, pectoral fin; *pv.f.*, pelvic fin; *v.f.*, ventral fin. (A, after Vardine; B and C, after Goode; D from Bull. U. S. F. C. 1895.)

Sub-Order IX. Anacanthini (3 families). These are the cod, etc. (Fig. 370).



Fierasfer acus

Hippocampus barbouri (sea horse)

Exonautes gilberti (flying fish)

Gadus morrhua (cod)

Fig. 370. Teleostei.

A, *Fierasfer acus* penetrating anal openings of holothurians. *D, an*, anus; *c.f.*, caudal fin; *d.f.1—3*, dorsal fins; *mx.*, maxilla; *pct.f.*, pectoral fin; *pmx.* premaxilla; *pv.f.*, pelvic fin; *v.f. 1* and *2*, ventral fins. (A, after Emery; B, after Bull. U. S. F. C. 1907; C, after Jordan and Evermann; D, after Cuvier.)

Sub-Order X. Acanthopterygii (78 families).

These include a great majority of our more common fishes, such as perch, bass, mackerel, flounders, gobies, shark-suckers, climbing perch, etc. (Fig. 371).

Sub-Order XI. Opisthomi (1 family).

These are the eel-like fishes.

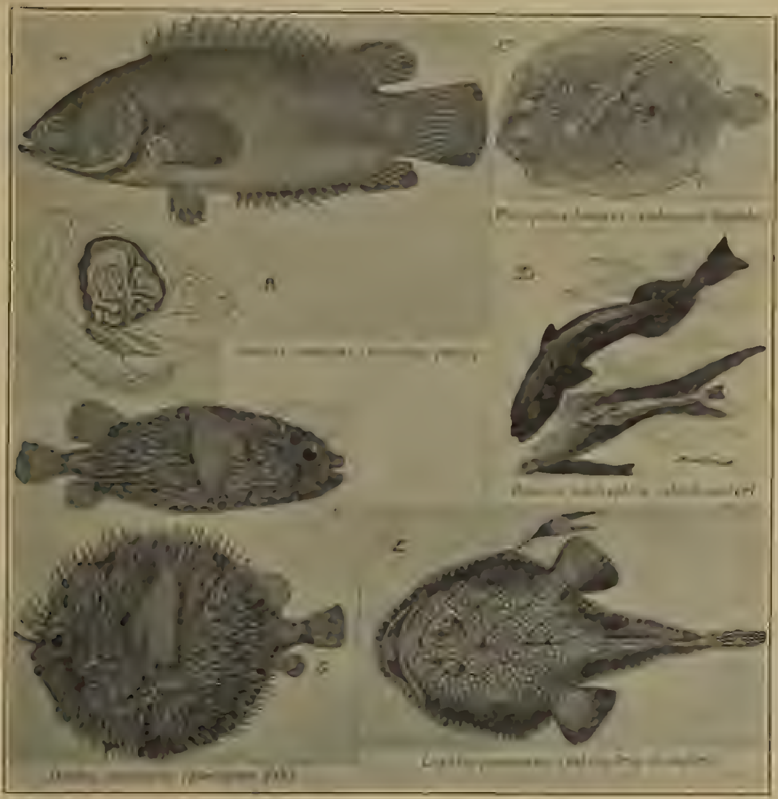


Fig. 371. Teleostei.

B, Dissection of head of Climbing Perch to show accessory respiratory organ; F, normal and G, inflated porcupine fish. (A and E, after Cuvier; B, F. and G, after Günther; C, D, after Baskett.)

Sub-Order XII. Pediculati (5 families).

These are the Anglers, Bathymal Sea-Devils, etc. (Fig. 371).

Sub-Order XIII. Plectognathi (7 families).

These include the file-fishes, trunk-fishes, puffers, porcupine fishes and sun-fishes. (Fig. 371).

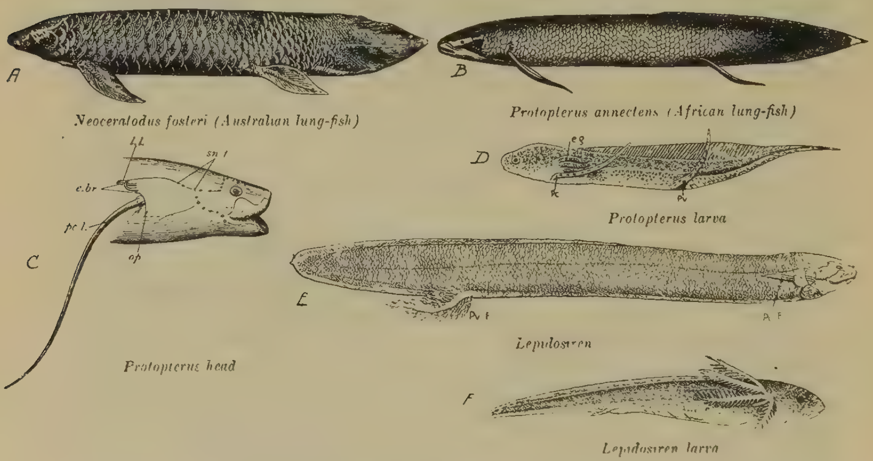
Sub-Class III. Dipneusti (Dipnoi) The Lung-Fishes (Fig. 372). (2 extinct and 2 living families. These include the **Neoceratodus**.

Protopterus and **Lepidosiren.**

The skeleton of these lung-fish is largely cartilaginous but there is a tendency toward ossification. The swim-bladder serves as lungs. The very young individuals have long, feather-like external gills.

Appendix to the True Fishes.

I. **Palaeospondylidae** (1 family between cyclostomes and fishes).
II. **Ostracodermi** (3 orders of 8 families, mostly armored fishes).
III. **Antiarchi** (1 family of mailed fishes).
IV. **Arthrodira** (1 family of mailed fishes).



Neoceratodus fosteri (Australian lung-fish)

Protopterus annectens (African lung-fish)

Protopterus larva

Protopterus head

Lepidosiren

Lepidosiren larva

Fig. 372. Dipneusti.

In C, *snt.*, sensory tubes; *l l.*, lateral line; *e.br.*, external gills; *pc.l.*, pectoral fin; *op*, operculum. In D and E, *eg.*, external gills; *Pc.*, pectoral fin; *Pv.*, pelvic fin. (A, after Günther; B, after Claus; C, after W. N. Parker; D, after Budgett; E and F, after Graham Kerr.)

It is well to note that 172 families of the 226 families of true fishes are members of the order **Teleostei.**

Of the **Elasmobranchii** there are 23 families now in existence and 9 extinct.

The **ganoids** and **dipnoi** number 22 families.

Amphibia.

Contrasted with fishes, the amphibia have **pentadactyl appendages,** while contrasted with reptiles, they possess **double occipital condyles.** There are external gills in the larvae, though these do not always persist. The adults breathe by lungs. The heart consists of two auricles, one ventricle, a conus arteriosus, and a sinus venosus.

Sub-Class I. Stegocephali.

These are the extinct amphibia, many of which attained considerable size.

Sub-Class II. Lissamphibia. (About 1,000 species, nearly 900 of which are frogs and toads. Figs. 315, 376).

Order I. Apoda (Gymnophiona) Limbless Amphibia. (Fig. 373).

These are also called **caecilians** and sometimes **"blind-worms."** They are without limbs or limb-girdles. They burrow in the earth and are found in warm climes. The cranium is like that of the reptile in outward appearance but the bones which constitute it are the same as those which go to form any amphibian cranium. The skin is smooth and slimy with many ring-like folds. There are as many as 200 to 300 vertebrae in some species. The eyes are rudimentary and probably functionless. There is a feeling-organ protruded from between eye and nose which serves to guide the animal. Some are oviparous, while others are viviparous.

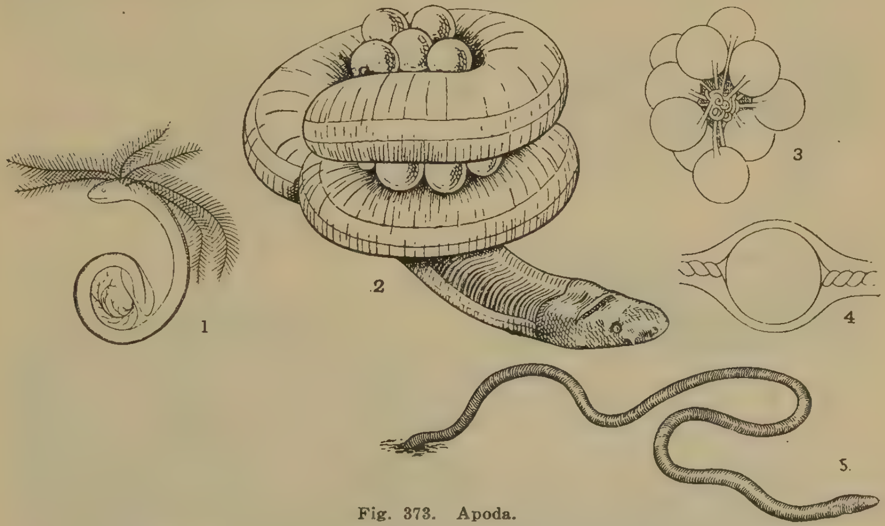


Fig. 373. Apoda.

Ichthyophis glutinosa. 1, nearly ripe embryo, with gills tail-fin, and with considerable amount of yolk; 2, a female guarding her eggs, coiled up in an underground hole; 3, a group of newly laid eggs; 4, a single egg, enlarged and schematised to show the twisted albuminous strings or chalazae inside the outer membrane, which surrounds the white of the egg. 5, *Caecilia,* emerging from burrow. (After P. and F. Sarasin.)

Order II. Urodela (Tailed Amphibia). (Figs. 315, 374).

These are the mud-puppies **(Necturus),** salamanders, newts, and efts. Many authors call all **urodeles with adult external gills, Perennibranchiata,** though the following grouping is the more common.

Family I. Amphiumidae (Fig. 374).

This family is without external gills in the adult stage. There are only two genera, **Cryptobranchus** and **Amphiuma** (Fig. 374).

Cryptobranchus alleghenienisis (Fig. 374), is the well-known "hellbender" of our Eastern States.

Cryptobranchus japonicus is the giant salamander of Japan.

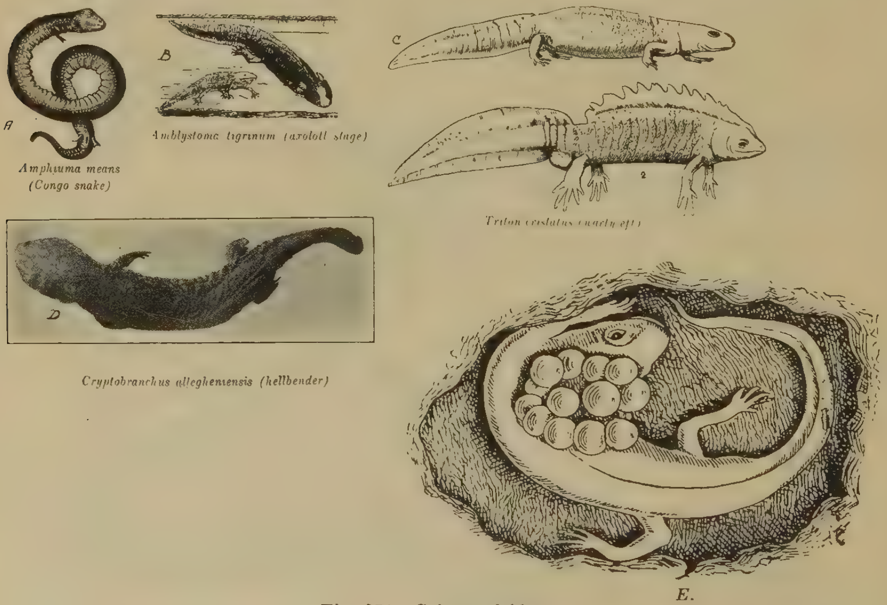
Amphiuma (Fig. 374) has only one species which ranges from Carolina to Mississippi in our Southeastern States. This is known as **Amphiuma means,** and is eel-shaped with much reduced limbs and a small pair of inconspicuous gill-clefts guarded by skin-flaps. Some of these animals are three feet in length, living in swamps and muddy water. The female protects the eggs by coiling about them.

Family II. Salamandridae. (Salamanders and Newts) (Fig. 374).

These animals have no gills in the adult stage. Practically three-fourths of all tailed amphibia belong to this family.

The most common type is the **Desmognathus fuscus** (Fig. 374). The female coils about the eggs when laid. The young, after hatching, look quite like adult forms.

Amblystoma tigrinum or "tiger salamander" (Fig. 374) is very common in North America. It has large yellow spots which may merge into broad stripes or bands. The ground color is black. It may be found in damp places under stones and logs, or even in cellars of houses. It is one of the classic forms used in the laboratory for various reasons, one of them being that it is an animal which becomes sexually mature while still in the larval stage, a condition called **paedogenesis** or **neoteny.**



Amphiuma means (Congo snake)

Amblystoma tigrinum (axolotl stage)

Triton cristatus (warty eft)

Cryptobranchus alleghemensis (hellbender)

Fig. 374. Salamandridae.

In C, 1, Female; 2, Male at the breeding season with well-developed frills. E, *Desmognathus fuscus* (American newt). Female with eggs in underground hole. (A, after Molder; B, from Cambridge Natural History; C, after Gadow, E, after Wilder.)

Another very interesting fact is brought out in the life of the larval forms of **Amblystoma.** The larva **itself** is called **Axolotl,** and was formerly considered to be a fully adult form. It is quite common near Mexico City. However, when some of the **Axolotls** were taken to Paris, and kept in aquaria, they metamorphosed into regular, full-fledged

Amblystoma. Not only this, but some of them could be made to revert back to the larval **Axolotl** form.

Salamander maculosa, commonly called the "spotted" or "fire salamander" is the most common of the European salamanders.

Salamandra atra is much darker than **S. maculosa** and is found in the Alps at altitudes from 2,000 to 9,000 feet. This animal is interesting in that it produces only two young at a time, which, while still in the uterus, feed upon the surrounding eggs and pass through their entire metamorphosis before being born.

Kammerer claims that **S. atra** will change to **S. maculosa** if brought to lowland waters and then after being kept there for several generations, and later returned to the higher altitudes, they well retain the breeding habits acquired as the lowland type. This fact has led some authors to insist that here is a case of acquired characteristics being inherited.

Diemictylus viridescens is the "vermilion spotted eft" or newt. It takes several years to reach the adult form. For three years it lives in water and has external gills. During this time it is green in color. Upon leaving the water it becomes yellow with vermilion spots, and at the breeding season returns to water and again becomes green.

Triton cristatus (Fig. 374) is the "crested newt." The male has a decided crest during the breeding season.

Family III. Proteidae. (The Mud-Puppies) (Fig. 375).

These have three pairs of fringed external gills throughout life and some authors call them **perennibranchii.**

There are only three genera with a single species each. Two of these genera occur in America and one in Europe.

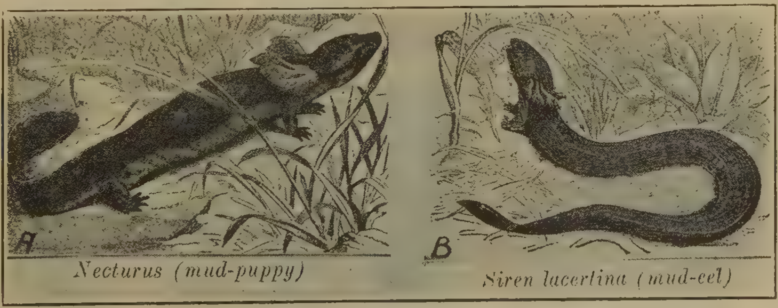


Fig. 375. Proteidae and Sirenidae.

(After Chapin and Rettger.)

Necturus maculatus is the common American "mud-puppy." It is assumed that this may be an animal which has remained in the larval stage.

Proteus anguineus (the Germans call them "olms") are blind, cave, mud-puppies nearly white in color. But, if brought into the light they become at first grayish and then jet-black.

Typhlomolge rathbuni, is a form quite like **Proteus,** and is found in subterranean caves and sometimes is brought up from deep artesian wells. They are found in Texas.

Family IV. Sirenidae. (The Sirens) (Fig. 375).

These have three pair of permanent fringed external gills, and the body is eel-like. **There are no hind limbs.** There are two genera each with a single species.

Siren lacertina, commonly called the "mud-eel." It may reach a length of thirty inches. It is black in color dorsally and lighter ventrally. It is found in the southeastern part of the United States.

Pseudobranchus striatus, is much smaller than **Siren,** hardly ever reaching a length of more than seven inches. It has one pair of gill-clefts and only three fingers. There is a broad yellow band along each side. It is assigned the lowest place among the urodeles.

Order III. Anura (Tailless Amphibia) (Figs. 315, 376).

These are the frogs and toads.

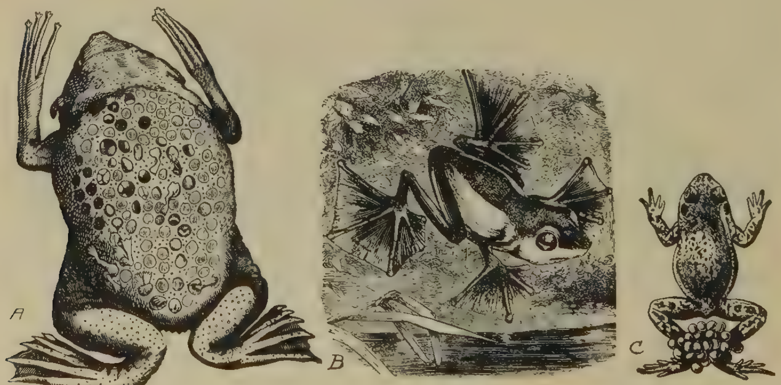
Sub-Order I. Aglossa.

These animals have no tongue.

This group is not yet commonly known as it occurs only in South America and in Africa.

Pipa americana (also known as the "Surinam toad," Fig. 376), has rather remarkable methods of carrying its eggs after they have been laid. There are holes in the back of the female into which they are deposited.

Xenopus, and **Hymenochirus** are the African genera.



Pipa americana — *Rhacophorus (flying tree-toad of Borneo)* — *Alytes obstetricans (obstetrical toad)*

Fig. 376. Anura.

A, *Pipa americana* with young in skin pockets of back. C, Male obstetrical toad with string of eggs. (A, after Ludwig; B, after Wallace; C, after Claus.)

Sub-Order II. Phaneroglossa.

These are the frogs and toads with tongues. There are seven families.

The best known of these families are the **Bufonidae** which are the common toads and the **Ranidae,** the "true frogs."

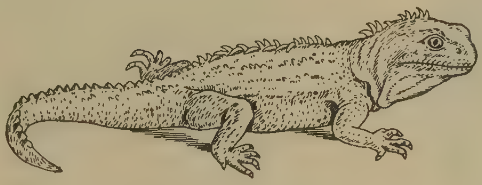
There is a peculiar species of toads in France and Switzerland called **Alytes obstetricans** (Fig. 376), in which the male takes the eggs when laid and wraps them around his hind legs, after which he deposits them in a hole in the ground. These eggs are then moistened by him with dew and taken out once-in-a-while in the water. When the eggs are ready for hatching, he takes them all to the water and remains with them until hatching is complete.

Class Reptilia.

There are four orders of living reptiles. These are cold-blooded vertebrates, breathing by means of lungs throughout their life cycle. **Lizards, snakes, crocodilians,** and **turtles** come under the heading of **Reptilia.**

The fossil records of the past show that the four living orders are but a small portion of the variations within this class which have continued their existence.

In the **Mesozoic era** (Fig. 245), commonly called the "**age of Reptiles,**" there have been found many skeleton-remains of immensely large lizard-like animals. In fact, the name given to the largest of these animals of the past is **Dinosaur** which means "terrible Lizard."



Sphenodon punctatum

Fig. 377. Reptilia.

(*Sphenodon* is considered the most primitive type of living reptiles.) (After Gadow.)

There were many flying reptiles at that time while **Plesiosaurs** lived in the water and had long paddles for swimming instead of legs.

Reptiles with wings are called **pterosaurs.** Some of their fossil remains show these animals to have been twenty feet from tip to tip of wings when spread. It is assumed that these animals so overspecialized various parts of their body that when great climatic and earth-changes came about, they could not cope with the new conditions. It has also been suggested that the eggs of many of these great animals may have been used for food by very small mammals which caused the largest of all beasts to die out entirely.

The reptile most closely resembling extinct forms is thought to be **Sphenodon** (Fig. 377). It is confined to a few small islands off the coast of New Zealand and is hunted and eaten by the Maoris. It is also called "tuatara" and lives in burrows. Externally it looks like a lizard, though skeleton and viscera are quite unlike those of other living lizards.

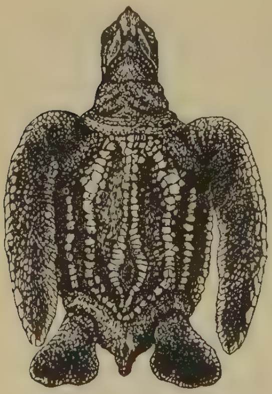
Order Chelonia. (Turtles and Tortoises).

These have a bony covering and toothless jaws. The covering consists of a dorsal or upper portion called a **carapace,** and a ventral **plastron.** These plates are soft in very young animals. The surface is covered with horny shields which Gadow believes to be phylogenetically older than the underlying bony plates. These latter do not correspond with the former in either number or position.

There are two sub-orders.

Sub-Order I. Athecae.

These are without a true carapace. There is only one living representative of this type, namely the **Leather-back Turtle,** known as **Dermochelys (sphargis) coriacea.** (Fig. 378.) Instead of the regular carapace there are five dorsal, five ventral, and two lateral dermal plates. The tail is rudimentary and the limbs are larger flipper-like paddles. Only large and very small specimens have ever been found. No one knows where they live between these stages.



Sphargis coriacea (leather-back turtle)

Fig. 378.

The only chelonian without a true carapace. (From Gadow.)

Sub-Order II. Thecophora.

These are the true turtles (Fig. 379) which are divided into two groupings known as **Cryptodira** to which group most of the turtles of the Northern Hemisphere belong. The head is retractile and the pelvis is not fused to the shell, while in Division II, are the **Pleurodira,** representing a large group of the Southern Hemisphere. These do not retract the head but bend it sideways under the shell. The pelvis is fused to the shell.

The more commonly known American Turtles belong to Division **Cryptodira.** The snapping turtles being members of the family **Chelydridae.** The skunk- or musk-turtle is a member of the family **Cinosternidae,** and the common pond tortoises are members of the family **Testudinidae.** The "tortoise-shell" turtle belongs to those commonly called "sea-turtles" and is a member of the family **Chelonidae.**

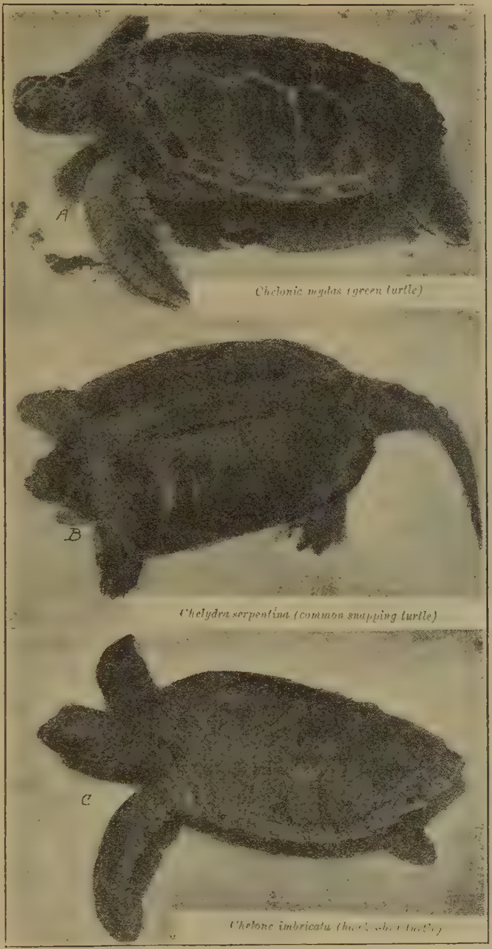

A
Chelonia mydas (green turtle)
B
Chelydra serpentina (common snapping turtle)
C
Chelone imbricata (hawksbill turtle)

Fig. 379. Chelonia.

A, grows to weigh 800 pounds; B, 40 pounds; C, smallest of marine turtles. This latter is the tortoise-shell turtle. (After Ditmars.)

Order Crocodilia.

Crocodilia are characterized by well-developed limbs, long tail, fixed quadrate bone, and teeth fixed separately in alveoli. The various extinct forms, however, do not have all these characteristics.

There are only two families of **Crocodilia** (Fig. 380).

Family I. Gavialidae.

There is only one living species of this family. It is called **Gavialis gangeticus.** It is found in the River Ganges and other large rivers of India.

Family II. Crocodilidae.

This family inludes both old and new world crocodiles and alligators. The latter animals do not grow as large as the crocodiles. The alligator is distinguished from the crocodile by having a broad, rounded snout.

Order Sauria. (Squamata.)

These are the lizards and snakes. Their main differentiating characteristics are: a movable quadrate bone which permits of a wide mouth-opening, a transverse cloacal aperture and double copulatory organs.

Division I. Lacertilia. (Lizards).

While normally the ordinary forms of lizards are scaly and have four well-developed legs, there are many species which do not have these characteristics. This latter type appear quite like snakes but the bones of the skull always serve to distinguish them. Then too, the lizards have no elastic ligament between the two halves of the lower jaw, as snakes have.

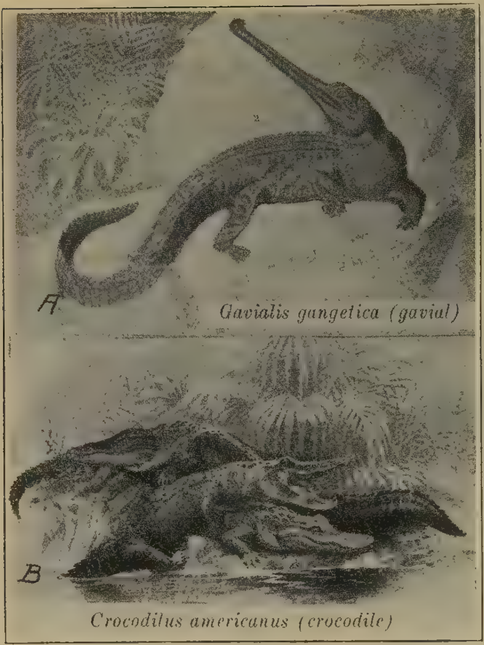

A
Gavialis gangetica (gavial)
B
Crocodilus americanus (crocodile)

Fig. 380.

Crocodilia. (After Baskett and Ditmars.)

There are three sub-orders (Fig. 381).

Sub-Order I. Geckones.

These are the primitive types having amphicoelous vertebrae (Fig. 404), and no bony temporal arches. They have dilated clavicles, separate parietals, eyes with movable lids, broad, fleshy, protrusible tongue, which is nicked at the end. Usually harmless. The tail is loosely articulated and comes off when seized although a new one grows quite readily

Sub-Order II. Lacertae.

Most modern lizards belong to this group. Their vertebrae are procoelous and solid. The ventral portions of the clavicle are not dilated.

There are **cursorial types, arboreal types, volant types,** an **aquatic type,** a **fossorial type** and an **ant-eating type,** so-called from their varying modes of life.

The Gila Monster **(Heloderma horridum)** of our Southwestern States is the only poisonous lizard known, while the **monitor (Varanus salvator)** grows to the greatest length, something like seven feet or more.

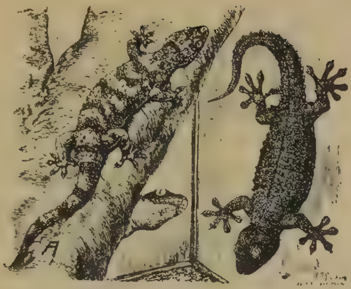
Sub-Order III. Chamaeleontes (Chameleons). (Fig. 382).

These animals are the ones so well known on account of their ability to change color, and the enormously long tongue by which they readily catch insects at a distance of some seven inches.

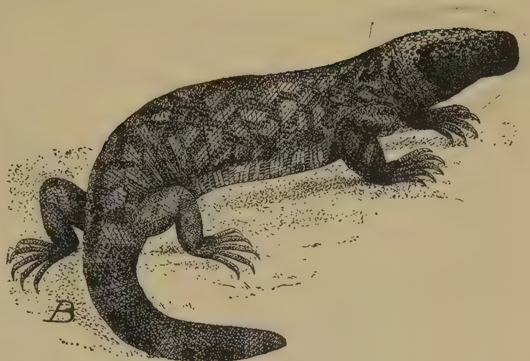
Chameleons are highly specialized, the body is laterally compressed, the tail is prehensile, and the toes are parted in the middle so as to be used for grasping. They are found mostly in Madagascar. One species is found in Southern Europe.

Division II. Ophidia (Snakes).

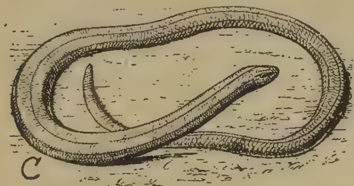
Snakes are really **Sauria** or **Squamata** in which the right and left halves of the lower jaw are connected with an elastic ligament, thus permitting the mouth to stretch greatly. They are usually limbless or have



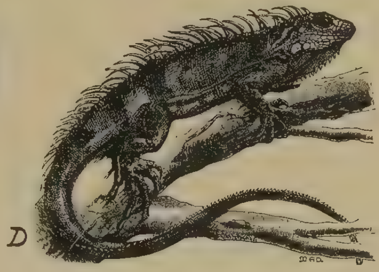
Hemidactylus turicus and Tarentola mauritanica (geckones)



Heloderma (Gila monster)



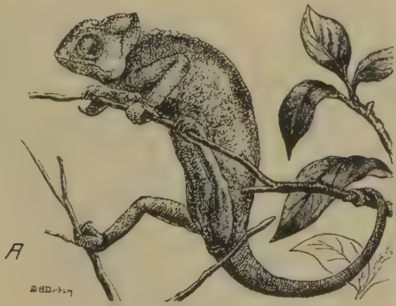
Anguis fragilis (limbless lizard)



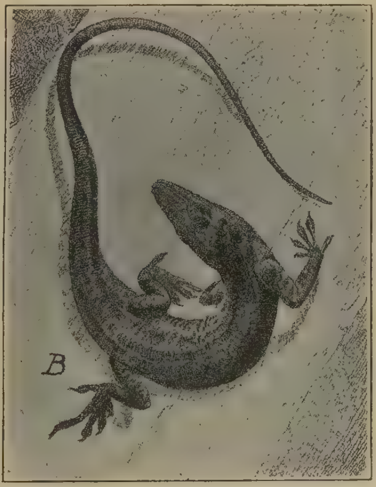
Iguana tuberculata (common iguana)

Fig. 381. Lacertilia.

(A and D, after Gadow; B, after Ditmars; C, after Shipley and MacBride).



Chamaeleon vulgarus



Anolis principalus (American chamaeleon)

Fig. 382. Chamaeleontes.

(A, after Gadow; B, Ditmars.)

rudimentary limbs under the skin as has the python. The eyes are without eye-lids.

Class V. **Aves.** (Birds).

These are closely related to the reptiles. In fact, reptiles and birds are often grouped together as **Sauropsida.** They have a single occipital condyle as do the reptiles. The heart of birds is, however, divided into right and left halves. Birds are warm-blooded. There is a fusion of the bones of the manus and there is the formation of a tibio-tarsus and tarso-metatarsus (intratarsal joint). Feathers cover the body.

Birds are commonly divided into **Ratitae** or "running birds" such as the ostrich, rheas, cassowaries, etc., which lack a **furcula** (wish-bone) and a **keel** (Fig. 418) to the sternum, and the **Carinatae,** or the "flying birds." These latter have the sternum keeled and the clavicles are united to form the furcula.

There are two extinct groups which had teeth.

Class VI. **Mammalia.**

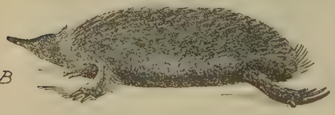
These are warm-blooded animals having a covering of hair, two occipital condyles, and milk-glands in the female.

Mammals are divided into two sub-classes.

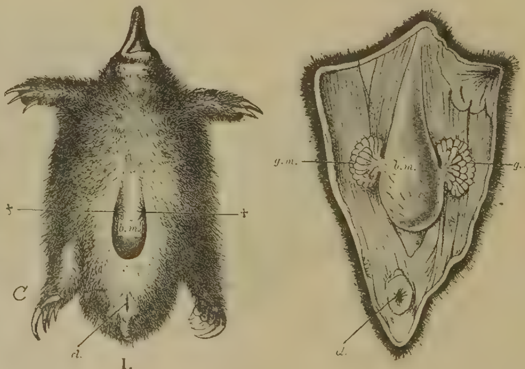
Sub-Class I. Prototheria, or egg-laying mammals.

Order I. Monotremata, which consists of two families (Fig. 383).

Ornithorhynchus anatinus (duck-bill)



Echidna aculeata (spiny ant-eater)



I. *Echidna hystrix* II.

Fig. 383. Monotremata.

C. Echidna hystrix. I, lower surface of brooding female; *II,* dissection showing a dorsal view of the marsupium and mammary glands; † †, the two tufts of hair projecting from the mammary pouches from which the secretion flows; *bm,* brood-pouch or marsupium; *cl,* cloaca; *g.m.,* groups of mammary glands. (A, after Shipley and MacBride; B, after Claus; C, after Haake.)

Family I. Ornithorhynchidae. (The duck-bill of Australia.)

There is **no corpus callosum** (Fig. 471), and the brain is the most primitive of all living mammals.

The eggs, two or three in number, and covered with a hard shell, are reptilian in form and are laid in a nest of grasses. The heat of the mother's body hatches them.

Family II. Echidnidae.

These are the Australian Ant-Eaters. There is a temporary marsupial pouch. Only one egg, about half an inch long, is laid at a time and placed in the marsupial pouch by the mouth of the mother. Here the young hatch in a very immature condition, the mother being obliged to remove the egg-shell after the young has come forth. The young **Echidna** obtains its food by licking the milk-like secretion exuding from the hairs in the pouch.

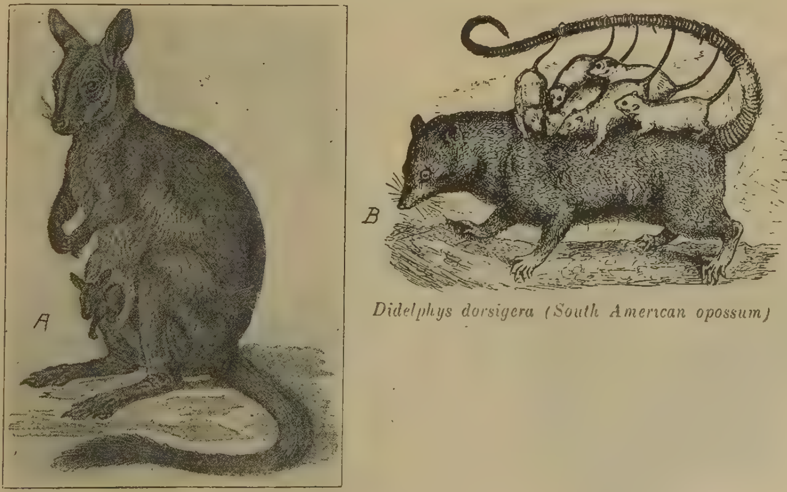
Sub-Class II. Eutheria.

These are the viviparous mammals which are divided into two divisions.

Division I. Didelphia (Metatheria) (Fig. 384).

These are the marsupials.

Order I.. **Marsupialia.** Mammals having a pouch to carry their young which are born in a rather immature condition. There is usually



Petrogale xanthopus (rock wallaby with young in pouch)

Didelphys dorsigera (South American opossum)

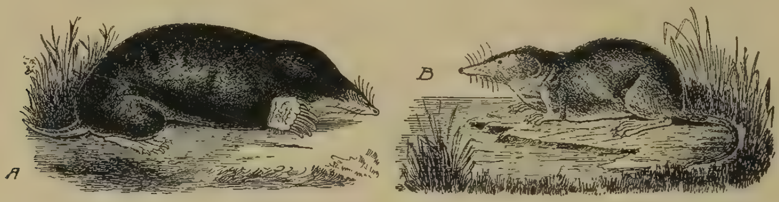
Fig. 384. Didelphia.

(A, after Vogt Specht; B, after Nicholson.)

no placenta. Australia furnishes us with most **Marsupialia,** such as the kangaroo, wombat, phalangerer, pouched mole, and many other forms, while the opossum is the only example in America.

Division II. Monodelphia. (Placental Mammals).

The young are never carried in a pouch, but a true placenta nourishes the unborn fetus.



Scalops acquaticus (common mole)   *Sorex vulgaris (common shrew)*

Fig. 385. Insectivora.

(After Coues.)

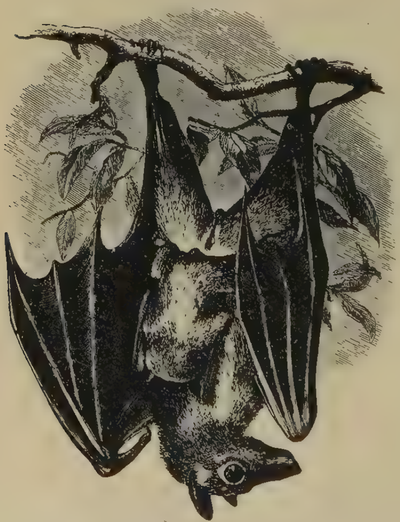
The placental animals are divided into the following **sections: Unguiculates, Primates, Ungulates,** and **Cetacea.**

Section A, Unguiculates. (Clawed animals).

Order I. Insectivora, such as moles, shrews, and hedgehogs (Fig. 385).

Order II. Chiroptera, such as bats (Fig. 386).

Order III. Carnivora, possess sharp teeth and claws. Under this heading come the cat, **(Felidae)** and dog **(Canidae)** families, for example, and many others.



Xantharpyia collaris (bat)

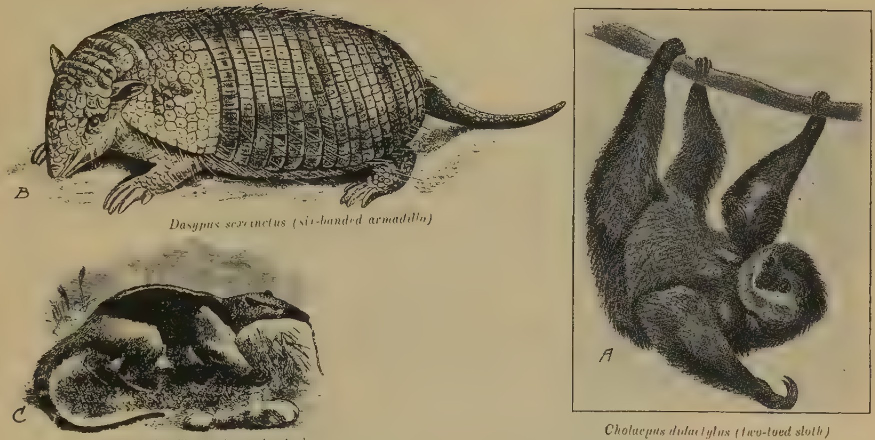
Fig. 386. Chiroptera.

(After Sclater.)

Order IV. Rodentia are the gnawing animals. Rabbits, guinea pigs **(Cavia),** rats, mice, squirrels, etc., come under this heading.

Order V. Edentata. This name means toothless, but the animals with the exception of the ant-eaters, belonging to this group do possess teeth. Different authors classify the **Edentata** in various ways. The animals usually coming within this group are sloths, ant-eaters, and armadillos. (Fig. 387.)

Section B, Primates. (Mammals with nails.)



Dasypus sexcinctus (six-banded armadillo)

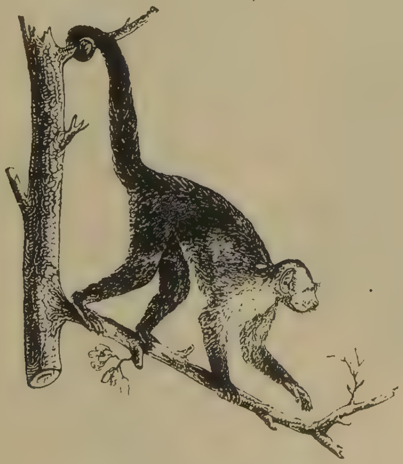
Tamandua tetradactyla (Tamandua ant-eater)

Cholœpus didactylus (two-toed sloth)

Fig. 387. Edentata.

(A and B, after Vogt and Specht; C, from Proc. Zool. Soc. 1871.)

Order VI. Primates. Mostly tree-inhabiting animals with nails on fingers and toes instead of claws or hoofs. The monkeys which are to be included under this heading are divided into **Platyrrhine** (broad-nostril) and **Catarrhine** (narrow-nostril) groups. The former are peculiar to the New World and the latter to the Old World. The higher apes belong to the Old World group. New World monkeys have a prehensile tail (Fig. 388) while no Old World monkeys possess



Cebus hypoleucus
(white-throated Sapajou)

Fig. 388.

Note the prehensile tail so characteristic of New World Monkeys.

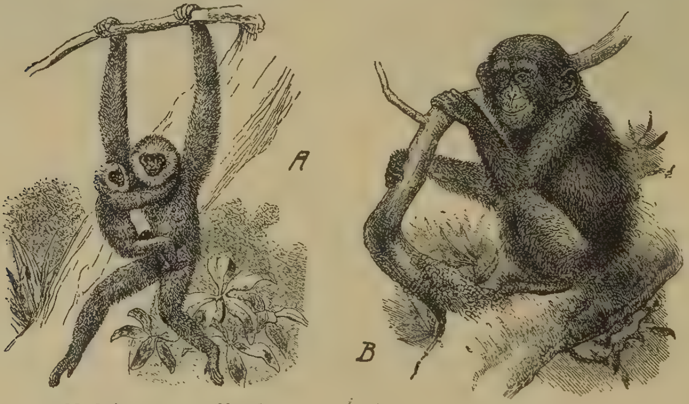
this. In the **anthropoid** or manlike apes **(Simiidae)** (Fig. 389), there is no tail at all.

Section C, Ungulates. (Hoofed animals).

Order VII. Artiodactyla (even-toed ungulates), are pigs, **(Suidae),** deer **(Cervidae),** giraffes **(Giraffidae),** cattle, sheep, goats **(Bovidae).**

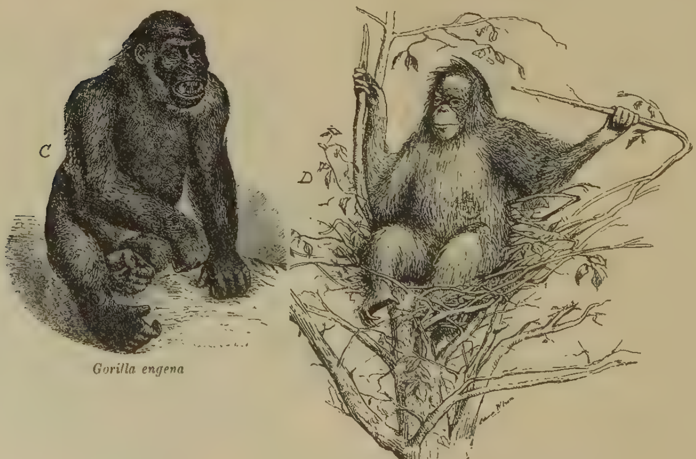
Artiodactyla are all terrestrial or mud-inhabiting animals, usually of large size, having hoofs on two or four toes. Their stomachs usually have several chambers and are peculiarly adapted for an herbivorous diet.

Artiodactyla are often divided into two groups:



Hylobates entelloides (dun-colored gibbon)

Pan (Anthropopithecus) troglodytes (chimpanzee)

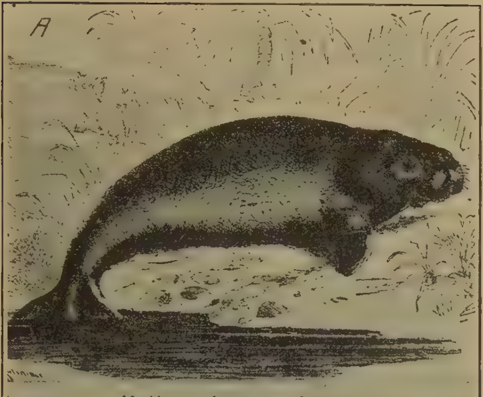


Gorilla engena

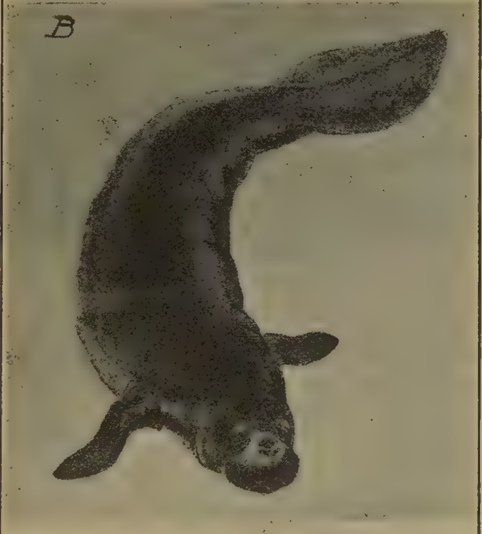
Simia satyrus (orang-ulan)

Fig. 389. Simiidae.

(A and B, after Flower and Lydekker; C, after Vogt and Specht; D, after Shipley and MacBride.)



Halicore dugong (dugong)



Manatus (manatee or sea-cow)

Fig. 390. Sirenia.

(A, from Brehm, B, from Ingersoll.)

Group I. Suina. (Swine-like).

All the swine family come under this heading including the hippopotamus which is really an aquatic hog.

Group II. Ruminantia. (Ruminants).

The animals belonging to this group swallow their food rapidly and later regurgitate it into the mouth for further chewing. Such animals are said to "chew a cud." Camels, llamas, antelopes, cows, giraffes, goats and sheep belong here.

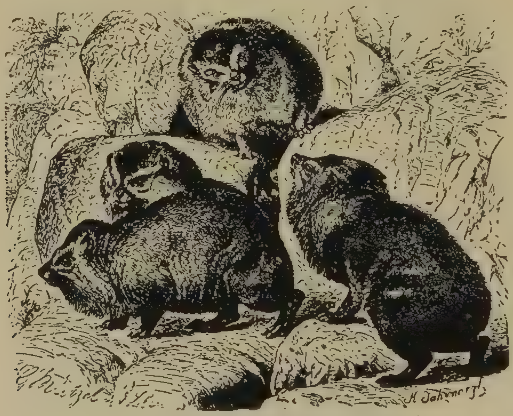
Order VIII. Perissodactyla. (Odd toed ungulates).

In this order the animal walks on the middle digit of fore and hind feet. The following three families make up the entire order: **Equidae** (horses, asses and, zebras). **Tapiridae** (tapirs); and **Rhinocerotidae** (rhinoceroses).

Order IX. Proboscidia (Elephants).

Order X. Sirenia (Sea-cows such as Dugongs and Manatees, Fig. 390).

Aquatic offshoots of ungulate stock.



Hyrax abyssinicus (coneys or hyraces)

Fig. 391. Hyracoidea.

(From Lull after Brehm.)

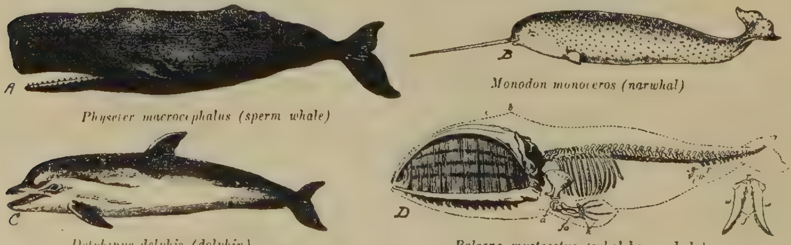
Order XI. Hyracoidea (Coneys, Fig. 391).

Short-eared, rodent-like, primitive ungulates, usually living among rocks, although some are tree-inhabiting.

Section D. Cetacea (Whales and Dolphins, Fig. 392).

Order XII. Odontoceti (Toothed-whales).

Examples of these are: sperm-whales, narwhals, beaked whales,



Physeter macrocephalus (sperm whale)

Monodon monoceros (narwhal)

Delphinus delphis (dolphin)

Balaena mystecetus (whalebone whale)

Fig. 392. Cetacea.

In D, *a*, upper arm; *b*, blow-hole; *fa*, forearm; *h*, hand; *p.th l*, small remains of pelvis, thigh, and leg; *r*, roof of palate; *w.w.*, plates of whalebone; *f*, whalebone fringe. (A, after Flower and Lydekker; B, after Cuvier; C, after Sedgwick; D, after Holder.)

porpoises, and dolphins. They have teeth but no whale-bone. They possess a single nostril or "blow-hole" and some of the ribs are two-headed.

Order XIII. Mystacoceti (Whale-bone whales).

These are also called **baleen** whales.

For convenience sake the following terms are often used:

Ichthyopsida.

This is a name given to **Cyclostomes, Gnathostomes**, and **Amphibia** combined. The distinctive characteristics of the **Ichthyopsida** are that all animals belonging to this group breathe by means of gills at some period of their life's history. They are therefore, **aquatic vertebrates.**

They are sometimes called **Anamniota** or **Anamnia** because they do not develop an **amnion**, and **Anallantoida** because they do not develop an **allantois.**

Sauropsida.

This is the name given to **birds and reptiles** combined. The distinctive characteristics of the **Sauropsida** are, that all animals belonging to this group breath with lungs and neyer develop functional gills: They are therefore **terrestrial vertebrates. Sauropsida**, together with the **Mammalia**, are called **Amniota** on account of their developing an amnion, and **Allantoida** on account of their developing an allantois.

Tetrapoda.

This is the collective name assigned to **all four limbed animals**, whether they are amphibians, reptiles, or mammals.

CHAPTER XLIX

THE INTEGUMENT.

As has been the custom of this book throughout, in examining any organism, we first observe its external appearance. It is thus the outer covering of the body which becomes the first object of our study. In fishes we therefore study **scales**; in the frog and the human being, the **skin**, while on other mammals, **fur**, and on birds, **feathers**. Yet, whatever forms such external parts may assume they are **a covering of the body**, and as such form what is called an **integument** ( ). **This term includes the skin or cutis and all the structures derived from it.** If an animal lives in water the effect of water upon such covering must be considered; likewise, consideration must be given to whether it lives in a cold climate or in a warm, and whether it lives in the air or burrows beneath the earth. All these things are bound to have their effects upon modifying an animal's outer covering.

Microscopically the integument of vertebrates consists of **two layers** (Fig. 393), an outer, **epidermis**, which is the remainder of the ectoderm after the nervous system has been separated from it, and a **deeper layer, the corium or derma** composed **of mesenchyme** which has been derived from the **somatic portion** of the **somite.** It is into this deeper structure that the nerves and blood vessels extend.

Accessory organs are developed in both layers, and may begin growth in one and extend through the other. In all cases, however, each element of the accessory organs has a very definite place of origin.

The **integumental glands** thus arise from the epidermis, though dipping down into the corium to receive a fibrous covering.

Pigment usually develops in the corium and often then migrates to the epidermis, although it does sometimes develop in the latter layer itself.

Blood vessels (except in the mucous membrane of the pharynx of lungless salamanders) develop in the corium.

Sensory nerve endings are quite freely distributed throughout the epidermis, but the more specialized forms remain in the corium, often pushed up into the epidermic zone in the form of papillae. The epidermis is thus a bloodless, protective, covering with but slight sensitiveness, all the more delicate structures being found in the lower layer.

Both skin layers have the power to form hard parts known as **exoskeleton.**

True bone, for example, develops from the corium, while **horn** and **enamel** originate in the epidermis.

Horny structures, such as hairs or feathers (Fig. 394), are formed from the epidermis alone, but, dip down into the richly vascular corium to obtain nourishment. The dermal scutes of ganoids, and the dermal bones of higher forms arise entirely within the corium. Teeth are composite structures composed of **dentine,** a hard sort of bone, from the corium, overlaid with **enamel** from the epidermis.

It is important that one does not confuse the term integument with mere portions of the integument; for example, the **epidermis** is merely an **outer histologic layer.** The **ectoderm** is merely **one of the germ layers** from which both integument and the nervous system arise. The **skin alone** on such animals as have feathers, scales or fur, likewise **would not be the integument,** but **both skin and its immediate outer covering** would constitute such protective substance. The following schematic arrangement is that commonly used in medicine:

INTEGUMENT.
- Epidermis.
  - 1. Stratum corneum.
  - 2. Stratum lucidum.
  - 3. Stratum granulosum.
  - 4. Stratum mucosum.
  - 5. Stratum germinativum (Malpighian layer).
  - **Secondary Epidermal Structures.**
    - Exoskeleton.
      - Hair.
      - Nails, claws, hoofs, beaks,
      - Feathers.
      - Epidermal scales.
      - Sensory nerve-endings
- Dermis. (Commonly called Corium).
  - 1. Papillary layer, made up of dense connective tissue.
  - 2. Reticular layer, made up of looser connective tissue.
  - **Secondary Dermal Structures.**
    - Glands.
    - Pigment.
    - Blood vessels.
    - Lymph spaces.
    - Nerves.
    - Dermal scales.

Note: The exoskeleton of vertebrates consists of **bone, horn** and **enamel.**

Bone originates in the corium **(mesodermal).**

Horn and Enamel originate in the epidermis **(ectodermal).**

In comparative anatomy the epidermis in turn is divided into two layers, the lower one being known as the **Malpighian layer** or **stratum germinativum** (Fig. 393). Usually this layer rests on the **corium** and is nourished by the fluids from such corium. The cells therefore grow outward as they divide, forming a second or outer layer, the **stratum corneum.** These outer cells being the ones which come in contact with the surrounding media, are worn away almost as fast as new ones are added from below. If these outer cells come off in large sheets we find such a condition as that of a snake shedding its skin.

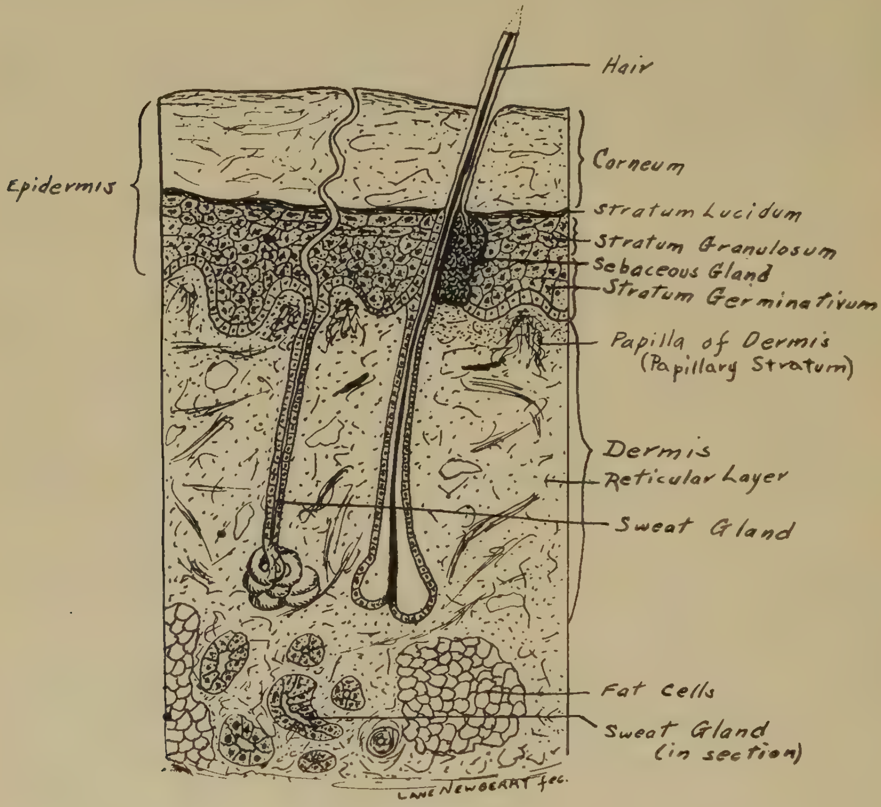


Fig. 393.

Diagram of a section through the skin of a mammal to show various layers, hair, and sebaceous and sweat glands.

In land animals the first layer of cells budding off from the Malpighian stratum seems a continuous sheet which is likely to be shed as a whole. This is called the **periderm** (Fig. 395). Older books call this the **epitrichium**, but as this word means "above the hair" it is not accurate when it refers to reptiles and birds which have no hair.

The Malpighian layer is that in and from which the **glands of the**

skin are formed, while the corresponding part of the ectoderm contributes to such **sensory structures** as the nose and ear.

The **hair, nails, claws, feathers** and other **outgrowths of the cutis** come **from the epidermis** (Figs. 393, 394). Land animals usually have a thicker epidermis than those which live in water. The latter keep the outer portion of the body constantly moist and so show less of the hardened or horny consistency which is found in animals living in the air. The **corium** lies **directly beneath the epidermis,** there being a loose layer of connective tissue separating it from deeper structures. The corium itself is a mass of fibrous connective tissue in which there is an intermingling of **elastic tissue, blood vessels, nerves, smooth muscle fibers,** etc. It is much thicker in mammals than in the lower vertebrates. It is the corium which is commonly known as **leather.** "Pigment cells may be found in both epidermis and corium. These are mesenchyme cells loaded with pigment which are frequently under the control of the nervous (sympathetic) system and can be altered in shape **(chromatophores),** thus producing color changes, which as in the chameleons, may be very marked."

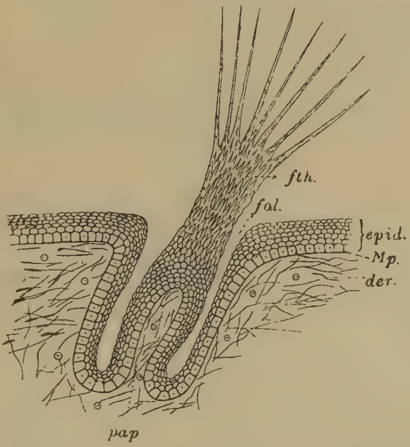


Fig. 394.

A diagram of a developing feather, highly magnified. *der.*, Dermis; *epi.*, epidermis; *fol.*, follicle; *fth.*, feather; *Mp.*, Malpighian layer of epidermis; *pap.*, papilla by the growth of whose epidermis the feather is formed. (From Shipley and MacBride.)

If the epidermis becomes **cornified,** scales are produced. This takes place by certain cells in both corium and epidermis beginning to multiply in certain definite regions. These thickenings become future scales by the **stratum corneum** turning into a horny material. In snakes and lizards these scales, together with all of the stratum corneum (even the covering of the eye), are periodically **moulted,** the separation taking place at the surface of the stratum Malpighii. In turtles and alligators there is a gradual wearing away of the surface.

Claws, hoofs and **nails** are closely allied in their manner of growth to scales (Fig. 396). In fact, a claw is formed by two scales. The dorsal one is called the **unguis** and the ventral the **sub-unguis.** The dorsal scale grows continually from a root and in mammals is forced over its bed. The unguis is curved both transversally and longitudinally, while the sub-unguis forms its lower surface.

In the human nail the unguis is nearly flat in both directions, and the sub-unguis is reduced to a narrow plate just beneath the tip of the nail. In the hoof the unguis is rolled around the tip of the toe, while the sub-unguis forms the ‘sole’ inside it. The ‘frog’ is the reduced ball of the toe which projects into the hoof from behind.

The comparisons in this semester’s work will be between **fishes, amphibians, reptiles, birds,** and **mammals,** as these represent the great **type-forms** of vertebrates.

FISHES

The life in water makes horny cornification very rare. The epidermis of fishes is therefore soft. “Pearl organs,” however, appear during the breeding season in some teleosts. Glands are quite abundant, the secretion furnishing the slime on the surface. Some groups of fishes also possess poison glands, usually in close relation to the spines of the fins. The elasmobranchs have large **pterygopodial glands** in the “claspers” of the males, although what these are for we do not know.

Photophores are some of the most interesting and striking of all epidermal organs. They are usually found in elasmobranchs and teleosts from the deep seas, where sunlight does not penetrate. In reality, they are formed very much like an eye by the cells of the Malpighian layer dipping into the corium. Here they are cut off from their origin, forming a deeper glandular layer, and the outer rounded body called the lens. The corium then forms a reflecting layer, which in turn is enclosed by a coat of pigment.

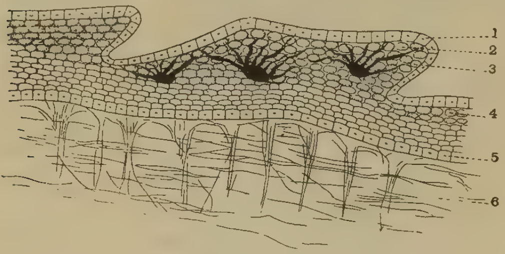


Fig. 395.

Section through the scale of a Lizard. 1. Peridermal layer. 2. Heavily cornified cells forming the scale. 3. Pigment cell. 4. Ordinary cells of horny layer. 5. Innermost Malpighian layer. 6. Dermis. (After Shipley and MacBride.)

In the myxinoids, there are many thread-cells in little pockets located in various portions of the skin. Each of these cells contains a long thread which is discharged upon stimulation, the threads forming a network in which the mucus secreted by the ordinary gland cells is entangled. Artificial pearls are made from “essence of pearl,” which is formed in the fibrous tissue of the corium of some fishes.

AMPHIBIA

The interesting point about these animals is that during the early larval stage, the epidermis is often ciliated, and two cells in thickness. There are numerous mucus and poison glands, sometimes enlargements of the neck called “parotid glands.” These occur on the **anura,** and there is likewise a gland on the back near the base of the tail. It will be remembered that the large lymph spaces under the skin of the frog make it possible to remove that animal’s skin quite readily. As amphibians and the lungless salamanders respire largely by the skin, the corium is richly supplied with blood vessels, which, at the time of the metamorphosis of anura, penetrate into the epidermis. It is at this time that the lungs are not yet functioning, and the gills are being absorbed. The stratum corneum is shed periodically, either as a whole, as in urodeles, or in patches. The "warts" of toads are partially cornifications of the epidermis. A similar hardening of the skin at the ends of the toes results in claws.

REPTILES

All these have horny scales and sometimes bony plates though some of the fossil groups have a naked skin.

Glands are rare, though some "turtles have scent glands beneath the lower jaw along the line between carapace and plastron; snakes and crocodilians have them connected with the cloaca, while the latter have others, of unknown function, between the first and second rows of plates along the back, as well as protrusible musk glands on the lower jaw."

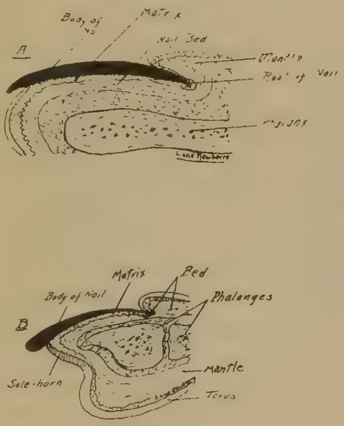


Fig. 396.

Comparison of human finger nail (A) and hoof of horse (B).

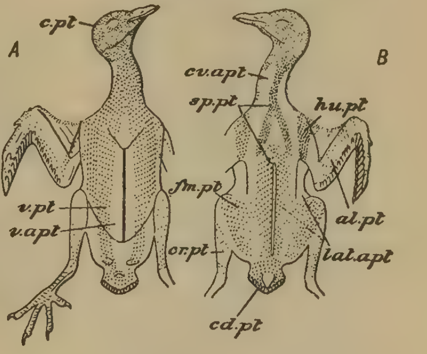


Fig. 398.

Feather tracts of the pigeon. *A*, ventral; *B*, dorsal. *al.pt*, alar pteryla or wing tract; *c.pt*, cephalic pteryla or head tract; *cd.pt*, caudal pteryla or tail tract; *cr.pt*, crural pteryla; *cr.apt*, cervical apterium or neck-space; *fm.pt*, femoral pteryla; *hu.pt*, humeral pteryla; *lat.apt*, lateral apterium; *sp.pt*, spinal pteryla; *v.apt*, ventral apterium; *v.pt*, ventral pteryla. (From Parker and Haswell, after Nitzsch.)

These latter are not true glands, as they produce no secretion, but cast out the living cells. Color changes are not remarkable except in a few snakes and lizards. Claws are common on the toes.

The so-called "femoral pores" on the under surface of the legs of lizards are not true glands. They are epidermal structures composed of horny cells, possibly having a sexual function.

BIRDS

The distinguishing characteristic of birds is that they possess feathers. Both layers of skin are quite thin, there being both scales and feathers developed from the epidermis, although there are extremely few glands. Some birds, like the ostrich, possess none, though a great many species have the so-called **uropygial gland** at the base of the tail which pours out an oily secretion for dressing the feathers. In a few **rasores** (scratching birds), there are modified **sebaceous glands** near the ear. The scales on the legs, as well as the claws on the feet and sometimes on the wings, are often said to be derived from reptilian ancestors.

Feathers are closely related to scales. There are several kinds of feathers, conveniently grouped under three heads:

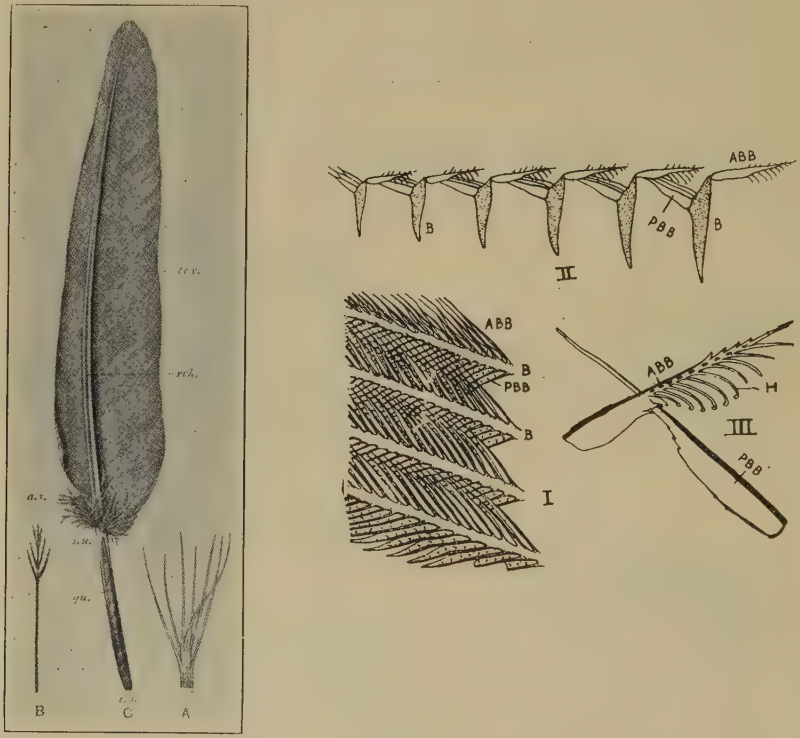


Fig. 397.

Feathers of a pigeon. *A*, Down feather; *B*, filoplume; *C*, quill feather. *a.s.*, Aftershaft; *i.u.*, inferior umbilicus; *qu.*, quill or calamus; *rch*, rhachis or shaft; *s.u.*, superior umbilicus; *vex.*, vexillum or vane. (After Borradaile.)

I, II, III.—Parts of a feather. *I.*, Four barbs (*B.*) bearing anterior barbules (*ABB.*) and posterior barbules (*PBB*); *II.*, six barbs (*B.*) in section showing interlocking of barbules; *III.*, anterior barbule with barbicels (*H.*) (After Nitzsch.)

(1) **Filoplumes** (hairy feathers).
(2) **Plumulae** (down feathers).
(3) **Plumae** (contour feathers).

It is the **plumae** that have the typical form consisting of shaft and vane. (Fig. 397.) The base of the shaft is the hollow quill in which a small amount of loose pith is found. The shaft or **rhachis** is solid, and a groove runs the length of its lower surface. This is the **umbilical groove.** The vane consists of lateral branches or **barbs** on either side, which have, in turn, still smaller side branches called **barbules.** These latter usually have small hooks at their sides and tips. These hooks interlock to give firmness and continuity to the whole vane. In down-feathers, where hooks are lacking, the barbs arise directly from the end of the quill, the barbs do not interlock, and no vane is formed. Hair-feathers consist of long slender shafts with a few terminal barbs.

Archaeopteryx, the oldest known fossil bird, had well developed contour feathers. In most birds, feathers are not equally distributed, but are gathered in tracts known as **pterylae** (Fig. 398), and separated by **apteria** or featherless regions where there are but few down or hair feathers. These feather-tracts vary, however, in different groups of birds, but are used to a considerable extent in classification.

There is a great similarity in the method in which the integument develops in the different type forms we are studying (Fig. 394). For example: "A down-feather begins as a thickening of the corium, pushing the epidermis before it. By continued growth this forms a long, finger-like papilla projecting from the skin. The corium extends into the outgrowth, carrying blood-vessels with it, while an annular pit, the beginning of the feather follicle, forms around the base of the papilla. Next, the corium or pulp of the distal part of the papilla forms several longitudinal ridges which gradually increase in height, growing into the epidermis and pressing the Malpighian layer above them against the periderm. As a rule, the stratum corneum is divided distally into a number of slender rods arising from the base (quill), which at last are only held together by the periderm. Then the pulp retracts, carrying with it the Malpighian layer. With the blood-supply removed, the epidermal parts dry rapidly, and the periderm ruptures, allowing the rods to separate, forming the down."

Contour-feathers are quite like down-feathers in their development up to a certain point.

It is to be remembered that the dorsal and ventral sides of the feather **were the outside and inside of the stratum corneum of the papilla.** Scales of lizard skin show extreme similarity in their development to the feather just described (Fig. 395). Many smooth muscle fibers act to elevate the feathers in the corium of birds, and there are also tactile or sense organs. The colors of feathers depend partly upon red, yellow, orange, brown, and black pigment deposited in them, but the iridescent colors are due to interference spectra.

MAMMALS

Mammals have a relatively thicker skin than other vertebrates (Fig. 393). There are many glands and considerable hair, except in a few orders such as the whales and sirenians. There are likewise horns and claws as well as scales, though the latter are not so conspicuous in the higher forms.

The corium is quite thick and is composed of irregular fibers interlaced with muscles, blood vessels, etc. Its outer surface often forms papillae or ridges, especially on the palms and soles. These ridges carry the epidermis with them. Several strata may usually be recognized under the epidermis, namely: a thick **Malpighian layer** at the base, then a thin **stratum lucidum** in which distinct cells cannot be recognized, and the **stratum corneum** on the outside. One or more other layers may be present. A cell must pass through all of these layers before it is worn from the surface of the skin.

HAIR

It is important that the histological structure of a hair (Figs. 393, 394) be compared with that of a feather already described.

Scales are found in many orders, usually best developed on the tail and feet. They are rounded, quadrangular, or hexagonal, the square scales being arranged in rings around the part, the others in groups of five known as **quincunx.** These latter are closely similar to the scales of reptiles. It seems, from recent investigations, that there is a close relation between scales and hair, since in mammals with scales, hairs are usually arranged in groups of three or five behind each scale; and in those without scales, the hairs are also grouped in the same manner. In the early embryo, the hairs are arranged in longitudinal rows so that grouping seems to come later.

GLANDS

These are of various kinds and types. The structural shapes and forms into which they may be grouped have already been studied in the frog and should be recalled, but we must also think of five divisions or groups, classified not according to structure, but according to function. Thus we have the following grouping:

(1) **Sweat** (tubular in shape extending from the Malpighian layer down through the corium where they are coiled).

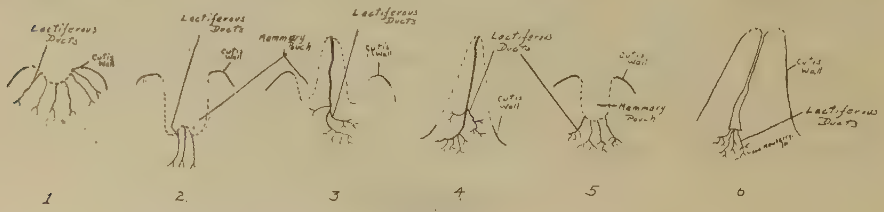


Fig. 399.

Schematic arrangement of varying types of mammary glands. 1, *Echidna*, primitive type; 2, *Halmaturus* (a genus of Kangaroo) forming pouch in lactation; 3, *Didelphys*, forming of nipple before lactation; 4, Same during lactation (quite like man); 5, Mammilary pouch in cow embryo; 6, in adult cow. (After Max Weber.)

(2) **Sebaceous** (acinous in shape), connected with each hair (Fig. 393).

(3) **Mammary** (modified tubular glands producing milk (Fig. 399).

(4) **Tarsal** or **Meibomian** (modified sebaceous glands in eyelid, producing oil to keep tears from overflowing (Fig. 400).

(5) **Anal** (acinous in form, commonly scent glands, secreting a substance either for sexual attraction or for protection (Fig. 400).

Glands are often also divided according to the method by which they furnish their secretions. First, into **necrobiotic glands** if they burst when liberating their fluids. The individual gland is then destroyed. And, second, **vitally secretory glands** if the secretions are poured through the walls of the gland while the gland itself remains functional for an indefinite period. In fact, this physiological distinction is often used to determine homologies when other methods cannot be used.

Each animal class seems to develop integumental glands in its own peculiar way, there being no definite and continuous history of gland development found throughout the various groups. Those animals living in the water, such as fish and amphibians, have glands that secrete protective substances which are often poisonous. The **Sauropsida** seldom have any integumental glands at all, and snakes have characteristic **cloacal glands** secreting a particular nauseating substance. Certain turtles have so-called musk-glands, probably for sexual attraction. In some lizards there is a row of so-called glands (really femoral pores) along the inner portion of the femora that secrete a substance at breeding time which hardens into short spines or teeth. In birds there are only the **uropygial glands** in the caudal region which furnishes an oil for the feathers.

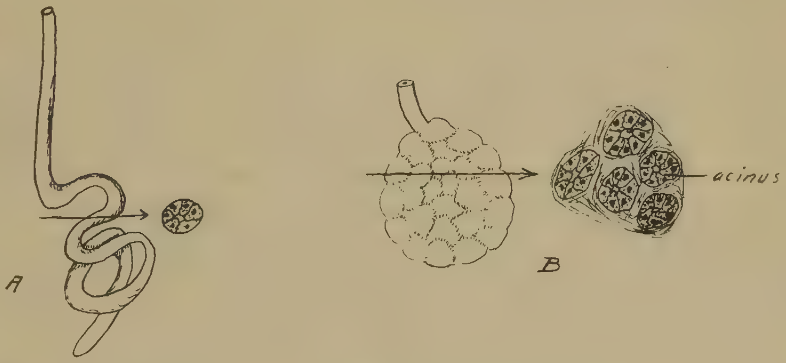


Fig. 400.

A, Sweat gland; *B*, Acinous gland. Complete gland and cross section. The cross section is cut at the level of the arrow. (Compare with Fig. 393.)

In mammals there are many and varying glands in the skin, but they may all be placed into two groups (Fig. 400), namely, the **sweat-**

glands, which are vitally secretory and tubular, and the **acinous glands,** many of which are lobed and necrobiotic, although both originally arise in connection with the hair.

The secretion from the sweat glands is usually thin and watery, although it may vary from this to a thick viscous pinkish fluid, the so-called "blood-sweat" of the hippopotamus.

The sweat glands may be found almost anywhere on the entire body or they may be localized. Localization takes place most frequently in the paws or on the palms of the hand and soles of the foot. Here they serve to assist in grasping a given object more solidly.

A modification of these glands also furnishes the oily secretion of the ear.

It probably has been observed that in hot weather horses sweat quite profusely while dogs do not. This is due to the fact that horses have sweat glands in the skin while dogs have not, so that dogs can only obtain the same relief that other mammals obtain, during such weather, by opening their mouths and panting, as it is only in this way that the constantly accumulating moisture finds its way to a surface where evaporation then brings about a cooling. Muzzles should, therefore, always permit the opening of the mouth.

There are some races of men, such as the Fuegians, who likewise have few sweat glands.

The acinous glands furnish an oily secretion, apparently for the original purpose of lubricating the hair, regardless of how far removed from this function such glands may ultimately come to be. These glands are called **sebaceous.** The **tarsal** or **meibomian glands** of the eyelids are practically hypertrophied sebaceous glands of the eyelashes. These meibomian glands pour out an oily secretion which lubricates the edge of the lids and prevents tears from overflowing. There are modified sebaceous glands in the various orifices of the body such as in the lips and about the anus.

Then there are groups of glands which are localized for quite specific functions, such as the anal-sacs of the skunk which secrete a protective substance, and the sexually attractive glands such as that of musk or civet. Musk is often used in the manufacture of perfumes.

Glands usually open as an elevation at a single place known as a glandular area. The milk-glands of mammals are typical examples, but there are cases where there is a sinking of the area so that instead of the young taking a nipple in their mouths, the lips of the sunken area fit closely about the nose of the young and thus prevent the secretion from being lost. Such is the case in **Echidna** (Figs. 383, 399). In the opossum the nipple is really a sac like that in **Echidna** but turned inside out.

It is a common observation that in many of the domesticated animals there is a row of nipples extending from axilla to the groin. In the embryo of many placental animals there is an entire ridge along which the mammary glands are to appear. In a short time there are suppressions at regular intervals which leave protruding nipples. These nipples in turn become reduced and eventually become actual depressions.

The varying position of the nipples in different groups of animals is due to the retention of some of the nipples in a particular region and the suppression of the remaining ones along this lateral ridge, which, as mentioned, extends from axilla to groin.

It is of interest that the aquatic **Sirenia** (Fig. 390) have pectoral mammary glands. They bear but a single young at a time and nurse their offspring by standing erect in the water while clasping the young in their flippers. It is supposed that many of the mermaid stories had their origin from an observation of this animal nursing its young.

It is by no means uncommon to find animals (including man) having a peculiar arrangement of nipples on their bodies. Supernumerary nipples are termed **hyperthelism** and supernumerary mammae are termed **hypermastism.** These supernumerary developments sometimes occur on the thigh and other parts of the body. They are considered **displacements** and **not reversions** if they occur in out-of-the-ordinary regions, and reversions if they occur in regions where they normally develop embryologically.

While rudimentary nipples occur in the male of placental mammals, and may even prove to be functional in some instances, monotromes and marsupial males do not develop them at all.

SCALES

As the dog-fish has what is called the **indifferent type of an exoskeleton,** it is this animal which forms the classic example for a preliminary study. Here we find imbricated rows of pointed scales (which merely means that one row of scales covers the intervals of the next row). (Fig. 401.) The scales of other fishes, as well as of reptiles, and even the feather papillae of birds, and the hair of mammals, are all arranged in a similar manner.

The scales of the dog-fish are said to be **placoid** (Fig. 401), which means that each has an approximately flat base from which a sharp-pointed cusp arises. This cusp is inclined in the direction of the free edge of the scale. When the scale is in place, the inclination is toward the posterior portion.

The scale itself consists of a core of dentine which is overlaid with enamel. In fact, the cusp is almost all enamel. The papilla from which nourishment comes to the scale lies beneath. In the embryo the scale forms between epidermis and corium, the dentine arising from the corium and the enamel from the epidermis.

In the selachians there are several rows of pointed teeth arranged quite like the scales on the surface. These develop from the same layers and in the same manner as the scales, and consist of a similar structure, so they are assumed to be merely placoid scales modified by different usage.

All higher vertebrates inherit teeth. In birds and turtles they are supposed to have been secondarily lost.

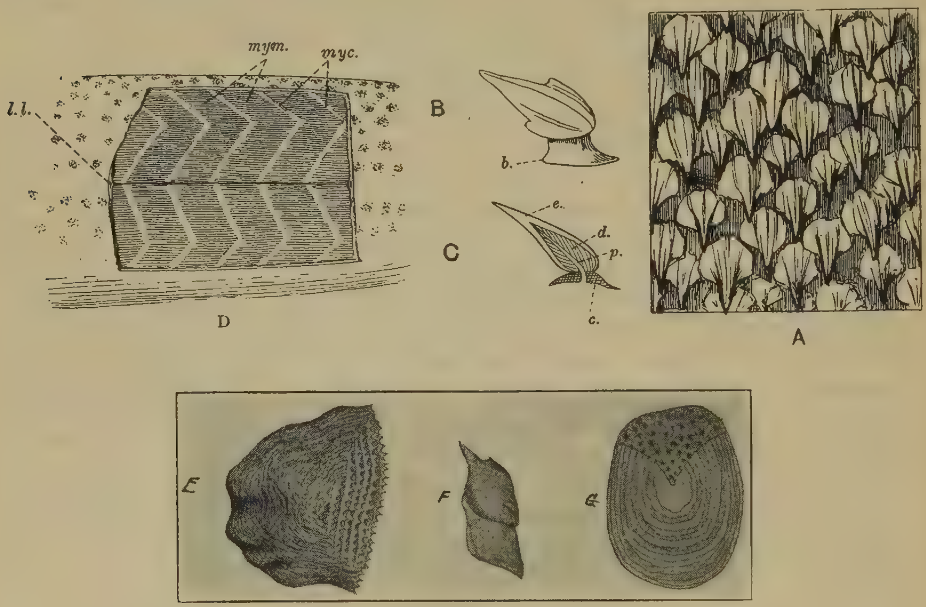


Fig. 401.

Placoid scales. *A*, A portion of the skin of the dog fish as seen under a hand lens; *B*, a single scale removed from the skin; *C*, the same in section (diagrammatic). *b.*, Base of the scale; *c.*, the same in section; *d*, dentine; *e.*, enamel; *p.*, pulp cavity. *D*, Part of the tail of a dogfish seen from the left side, with a piece of the skin removed. *l.l.*, Tube of the lateral line; *myc.*, myocommata or septa of connective tissue; *mym.*, myomeres. (After Borradaile.)
E, ctenoid; *F*, ganoid; and *G*, cycloid scales. (From the Cambridge Natural History; *E*, *F* after Günther; *G*, after Parker and Haswell.)

Ganoids (Fig. 368) develop their scales (Fig. 401) from the corium alone, the epidermis playing no part. Consequently the ganoid scale is all dentine. Ganoid scales are shiny, which is the very meaning of the term "ganoid." They are usually rhomboidal in shape and do not possess a cusp. In the sturgeons (Fig. 368) the scales consolidate into large bony shields called **scutes.** The former **mailed** or **armoured fishes** merely carried this consolidation to great extremes and the plates were continuous. In the sturgeons the plates are not continuous but are placed in rows along the back and sides so that there are large areas unprotected.

It is important to note at this point that in all ganoids (Polypterus, sturgeons, paddle-fishes, gar-pikes, and bow-fins, Fig. 368), the plates or scutes cover the entire head. The coming together of the edges forms sutures, while the structures lying between the sutures are commonly called the **dermal bones** of the skull.

Frontals, parietals, maxillaries and **squamosals** are found in all higher groups, though the opercular and rostral series disappear entirely. Most of the orbital series also disappear, with the exception of the lacrimal. Then, too, there are the dermal bones of the mouth cavity such as **vomers, palatines,** and **parabasal,** which are supposed to have retained the original character inasmuch as teeth often form on and in these bones.

In the higher forms the dermal bones, however, arise from various centers of ossification in the cutaneous mesenchyme, and while this difference has been explained as a curtailing of the previous race history, it is quite likely that there is little difference between dermal and cartilaginous bone formation in the highest mammalian forms, the dermal being merely more "stretched out" portions, as will be learned when the endoskeleton is studied.

Scales in the teleosts, although often **rhomboid** when quite young, become circular later and are then called **cycloid. Ctenoid scales** are quite similar to **cycloid** except that they are set in **diagonal rows** in pockets of the dermis with their free edges overlapping. (Fig. 401.)

Amphibians do not have scales and hard exoskeletons, although there are extinct forms in which the body was covered with them.

In reptiles the scales arise only from the epidermis and are therefore composed of horn or keratin. There is no trace of bone in them. The corium, however, furnishes the nourishment to these keratin scales, although it does not furnish any of the hard parts. There is no definite knowledge as to the relationship between the scales of reptiles and those of fishes.

Reptiles also have other integumental structures beside the keratin scales, namely: spines, combs, and claws; all, however, also made of keratin.

The birds are structurally and developmentally quite like the reptiles in that they possess feathers which are homologous to the reptile scales, and in having their beaks and claws composed of keratin. There have been toothed-birds in the past, and it is said that tooth-germs have even been found in the embryonic jaws of some of our modern birds.

In mammals, while there are tiny scales covering the body, these are seen as definite hard structures mainly on the claws, tails, and sometimes on the backs of such animals as the armadillos (Fig. 387). They are always only epidermal in origin. In the armadillos the corium secondarily supplies the hardening portions so that the covering of those animals becomes very thick, hard, and osseous.

It is assumed, very often, that formerly all mammals were covered by hard scales because the hair arrangement of mammals is quite like that of the scales. For example, on the tail of a rat, the scattered hairs will appear among the scales in a very definite relationship, namely, a group of three hairs (one medial and two lateral) will project beneath the margin of each. The median hair is the longer and stouter. In addition to this, there are similar arrangements of hairs in groups of three even upon areas not definitely associated with scales. The hairs, however, are arranged in an imbricated series like scales. Even where the hair is very thick, and forms a heavy fur, this arrangement can often be made out.

As scales in their simplest form are tiny elevations, the pads on mammalian feet are often used to illustrate the arrangement and transition of scales in different mammalian groups.

These pads are usually eleven in number, five for the tips of the digits, four for the distal margins of palm and sole beneath the interdigital intervals, and two for the wrist or ankle.

The scale rudiments are arranged in rows upon these pads. They fuse to form "friction ridges," so-called because they prevent the animal from slipping (Fig. 402). These friction ridges are always arranged at right angles to the direction in which there is considerable tendency to slip. In the arboreal types of mammals, such as the lemurs and monkeys, the scale rudiments are arranged in concentric circles as in such animals there is a tendency to slip in any and all directions. The ridges form only on the actual contact surfaces.

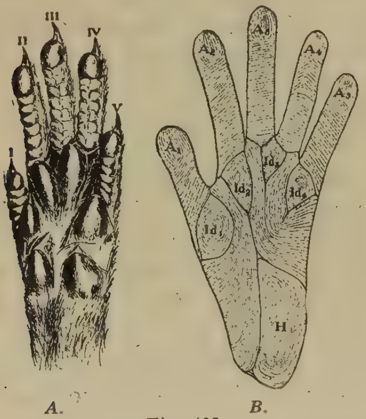


Fig. 402.

Ventral view of the palm of the hand of an insectivore and of a primate to show correspondence between relief and arrangement of friction ridges. *A*, *Crocidura coerulea* (shrew-mouse). Forepaw showing walking-pads enclosed by triangular folds of skin. *B*, *Macacus sp?* (Old World monkey), Hand, covered by friction ridges, the arrangement of which corresponds to the relief of *A*. The pads are represented by concentric circles, and the triangular folds by triradii. These latter features are here designated by heavy lines, although in the animal they are no more conspicuous than the others. (From Wilder after Miss Whipple.)

While **structure** always **determines function,** yet in integumental studies we have found that **function** very decidedly **modifies** the various **structures,** and later, we shall see that such modification is not confined to integument alone.

Now, to be truly scientific, means to retain an open mind to all truth wherever and whenever found. But our prejudices and wishes all too often influence us as readily toward a too conservative as toward a too radical point of view. We must face the facts as they are, pleasant or unpleasant, but we must not forget that **many different interpretations can be drawn from the self-same facts.** An example of this is brought home at this very point.

There is no question about the facts so far presented, which anyone can demonstrate for himself. The question that presents itself is simply this: Does it follow that because a bird has all the characteristics of a reptile, **plus some additional features**, that, therefore, it had reptile ancestors?

If one accept the so-called Haeckelian law of Biogenesis, that each individual in the embryonic stage passes through the adult stages of the race to which it belongs, then such a conclusion is valid; but, if we remember that all this so-called law means is that all forms pass through **similar** stages, the higher forms then continuing, while the lower ones remain stationary, another interpretation is still more valid. And our difficulty is by no means lessened when we remember that biologists at large are agreed that acquired characteristics **are not transmitted**. What, then, becomes of even a reasonable explanation of how any modifications can be carried on from parent to offspring?

Still further, we have seen from Professor de Vries' work that all newly appearing structures may be but the return of some **recessive** portions which have long lain dormant, while in the so-called **rudimentary structures** there is always the alternative of considering such structure an **overgrowth** or a **hypertrophy** of some smaller organ valuable at some time in embryonic life, or, it may even be a true remnant of a structure no longer needed by modern methods of life, modern foods and modern environment. Or, still a third alternative suggested by Professor Bateson, that just as a complex structure is **the more complex, the smaller and simpler it can be made to appear**, so the original fertilized egg-cell, from which an entire vertebrate develops, is much more complex than the finally completed body, because the single cell had all the possibilities of the complete body within its tiny self, and consequently, we are always really losing something as development proceeds.

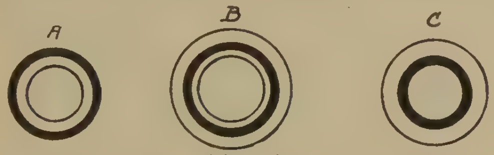


Fig. 403.

Diagram to show growth of bone. *A*, animal recently fed madder which causes a layer of bone (black) to be colored by the dye; *B*, no madder fed for a time, when a deposit of colorless bone on outside of colored layer is formed; *C*, later the outer layer becomes thickened and the inner layer is absorbed.

What is meant by a **normal development** of a cell into what it is later to become, is simply, that commonly, certain obstacles are removed by which these possibilities can come forth. If then, either environment (external or internal), food, atmosphere, position, injury, or chemical stimulus removes certain factors which hold back growth, any such possible factor already present in the cell may come forth; but its possibility must have been already present in the primitive cell.

This is well shown by the fact that normally the skin finishes growth at a certain time, but if a portion of skin is torn, the injury stimulates the connective-tissue cells which then divide and fill the wound with scar-tissue, that is, the original injury **removes an obstacle** to such connective-tissue-cell's growth. What particular factors, then, can be said to explain modifications? We do not know.

It is the province of science to press a problem further and further back and thus raise more problems. There is, and can be, **nothing absolute about any scientific interpretation.**

The student, as does the average man, wants something definite, something he can be sure of; but this is just what he cannot find in any biological study; and, unless he can appreciate this and still love science —science is not for him.

If he should nevertheless go into a scientific field such as medicine or dentistry, he will be a practitioner who will ever seek and follow the opinions of the least scientific and least trustworthy men, simply because these speak with definiteness and absoluteness, albeit, likewise with absurdity.

CHAPTER L.

THE ENDOSKELETON

By the term skeleton we mean all **hard parts used for support and protection** outside of what has already been termed the **integument. The skeleton develops only from mesenchyme.** It will be recalled that after the mesoderm has divided into a somatic and a splanchnic layer, these two layers together are called **mesothelium** to distinguish them from the mesenchyme, which, while also lying in the segmentation cavity, develops as **separate cells from both the mesothelium and the entoderm.** Some even believe that ectoderm has a part in its formation.

When bone forms from cartilage the lime salts may be laid down on the inner portion of the **perichondrium** and from there invade the cartilage. This is called ossification by **ectochondrostosis.**

In the other way in which bones form from cartilage, the osteoblasts are formed from the more interior cells, and then with this group of osteoblasts as an ossification center, ossification extends in all directions. This latter method is known as **entochondrostosis.**

Often the long bones increase by smaller bones forming and then becoming attached to the ends of the long bones. Such joining is called an **epiphysis.**

If madder is fed to an animal the actual bone formation is colored. This makes it possible to see just how the new bone is formed. The new bone is laid down outside of that already grown, and with such growth the "marrow cavity" becomes larger by a resorption of the bone which has already formed. The osteoblasts are laid down in between the newly forming layers of bone (Fig. 403).

THE VERTEBRAL COLUMN

We have already seen in our study of the embryology of the frog and chick how the centra of the vertebrae are formed around the notochord and that possibly some parts of the chorda remain as the intervertebral discs. Here we are to study and compare the adult form in the various groups.

The most complete vertebrae may be found in the tails of some of the lower vertebrates. Figure 404 shows a comparison of several types.

It will be noticed that dorsally there is a neural **arch,** while ventrally a similar outgrowth from the centrum is known as the **haemal arch,** while the pointed end in each case is known as a **spine.**

The haemal arch is quite incomplete or even entirely absent in the regions anterior to the tail.

In the higher vertebrates (Fig. 404) there are articular processes.

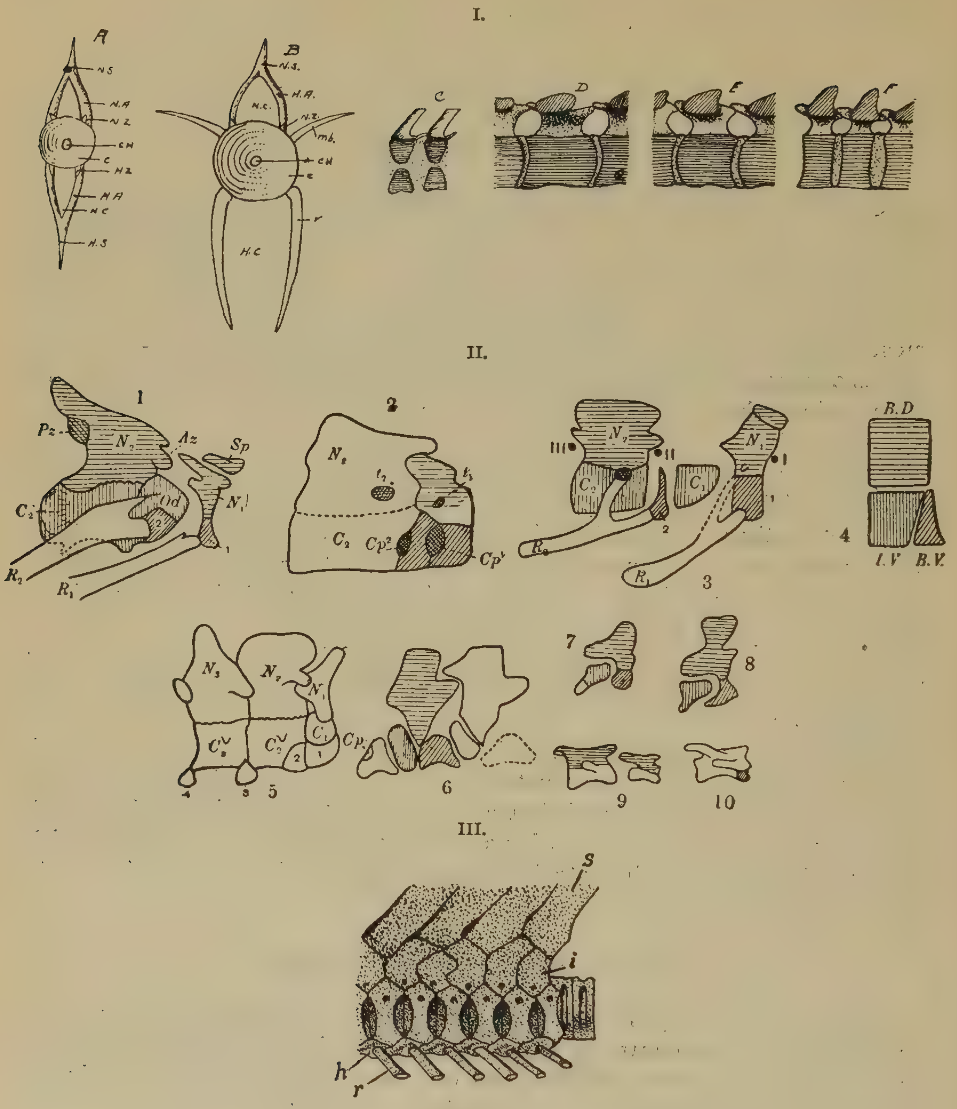


Fig. 404.

I, A and *B*. Diagram of a vertebra of a bony fish. *A*, caudal; *B*, trunk; *C*, amphicoelous; *D*, procoelous; *E*, opisthocoelous; *F*, amphiplatyan vertebrae. The head is supposed to lie at the left. *c*, centrum or body of vertebra; *ch*, notochord; *h.a.*, haemal arch; *h.c.*, haemal canal; *h.s.*, haemal spine; *h.z.*, haemal zygapophysis or articulating facet; *m.b.*, intermuscular bone; *n.a.*, neural arch; *n.c.*, neural canal; *n.s.*, neural spine; *n.z.*, neural zygapophysis; *r*, rib.

II. Composition of vertebrae of Reptiles, illustrated by the first and second cervical vertebrae. (1) Atlas (first cervical) and axis (second) vertebrae of Crocodile. (2) Atlas and axis of *Metriorhynchus*, a Jurassic Crocodile. (3) Analysis of the first two vervical vertebrae of a Crocodile. 2, second basiventral complex or "intercentrum" continued upwards into the meniscus or intervertebral pad. (4) Diagram of the fundamental composition of a Reptilian vertebra or other amniotic, gastrocentrous vertebra. (5) The first three cervical vertebrae of *Sphenodon*. (6) Trunk-vertebrae of *Eryops*, a Permian Proreptile, typically *temnospondylous*. *cp*, articular facet of the capitulum of a rib. (7) The complete also called **zygapophyses,** both on the anterior and posterior sides of each vertebra, and usually **transverse processes** extending laterally in the planes of the original divisions between the muscles.

Where true ribs occur, there are two additional transverse processes to which these attach.

The centrum where it meets with the intervertebral disc, has four distinct forms (Fig. 404).

If the face of the centra at each end where it is to meet with the intervertebral disc of the centra lying immediately anterior and immediately posterior to it (as in fishes), is **hollow** at both ends, it is called **amphicoelous** (Fig. 404). If one end is like a ball, namely, convex, and the other concave, so that the ball-like portion can fit into it, the condition is known as **procoelous** if the socket lies on its anterior surface, and **opisthocoelous** if on the posterior surface, while if the ends of the centra are flat, as they usually are in mammals, such a condition is known as **amphiplatyan.**

The arches of the vertebrae form first (Fig. 352), and the centra later, and the sclerotome divides into a caudal and cranial half which thus makes possible an advantageous condition to the animal in permitting interaction of skeleton and muscles (Fig. 305).

It must be remembered, however, in this connection, that in some animals, normally, and in others abnormally, the two halves of the sclerotome may unite (as in some fishes), and thus not have this interplay of muscles; or two neural arches may form by the rudiment which normally becomes one arch, dividing as does the sclerotome, and thus produce a greater quantity of vertebrae than usual. And, not only may this happen to the neural arches, but also to the centra. In fact, almost any variation in the spinal column may be accounted for by an embryological condition remaining in the adult form.

As the ventral nerve root usually penetrates the caudal division of the halved sclerotome, and the dorsal root passes between the two divisions of each sclerotome but penetrates the cranial portion, one can tell in the adult, from following these nerve roots, which of the adult structures come from cranial and which from caudal halves.

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atlas of an adult *Trionyx hurum.* The second basiventral (intercentrum) is attached to the posterior end of the first centrum which, not being fused with the second centrum, is not yet an odontoid process. (8) The complete atlas of an adult *Trionyx gangeticus,* still typically temnospondylous. (9) The first and second cervical vertebrae of an adult *Platemys.* (10) The complete atlas of a *Chelys fimbriata.* *Az,* Anterior zygapophysis; *B.D,* basidorsal; *B.V,* basiventral; C_1, C_2, C_3, first, second and third centra, formed by the interventralia; Cp^1, Cp^2, articular facets of the capitular portions of the first and second ribs; *I, V,* Interventral; N_1, N_2, N_3, first, second and third neural arch; formed by the basidorsalia (*B.D*); *Od,* odontoid process (which is the first centrum); *Pz,* posterior zygapophysis; R_1, R_2, ribs; *Sp,* detached spinous process of the first neural arch t_1, t_2, tubercular attachments of the first and second ribs; 1, 2, 3, 4, "intercentra" (which are the basiventrals); *I, II, III,* position of the exit of the first, second and third spinal nerves.

III, Trunk vertebrae of a tropical Skate. *h,* haemal process; *i,* intercalary plate; *n,* neural process; *r,* rib; *s,* spinous process. (*II,* After Gadow. *III,* from Kingsley after Dumeril.)

The different shaped ends of the centra which have already been mentioned are brought about after the vertebrae are quite definitely formed. The centra with their arches are in a quite definite position and the centra cannot therefore grow any more except at the ends. These may have more substance laid down in the intervertebral regions, however, and thus ultimately come to be amphicoelous, procoelous, opisthocoelous, or amphiplatyan.

REGIONS OF THE VERTEBRAL COLUMN

The regions of the spinal column are:

(1) **Cervical.** The neck region, either without ribs of any kind or the ribs are smaller than in the other regions.

(2) **Thoracic.** These have distinct ribs attached.

(3) **Lumbar.** Following the thoracic, and without ribs.

(4) **Sacral.** This region includes one or more vertebrae with which the pelvic girdle is connected.

(5) **Caudal.** The tail-portion immediately following the sacrum.

These divisions are quite distinct in the higher vertebrates, but in the lower, any and all combinations may form, so that the ribs may extend almost the entire length of the spinal column. In such cases all vertebrae having ribs are called **dorsal.**

In fishes, snakes, and whales, the sacral region cannot be distinguished, and in the fishes the dorsal and cervical vertebrae are quite indistinguishable. In this latter case there are, therefore, only trunk or abdominal vertebrae, and caudal vertebra, the line being drawn where the haemal arches begin to have ribs attached.

The first cervical vertebra to which the skull is articulated is called the **atlas** in all higher vertebrata, while the second cervical vertebra, at least in the amniotes, is called the **axis** or **epistropheus** (Fig. 404).

In mammals the atlas can always be distinguished by the two anterior articulating surfaces for the two condyles of the skull, and the axis, by the tooth-like projection known as the **odontoid process,** on which the atlas turns.

It is interesting to note that embryologically, this tooth-like process develops from the atlas, but then separates and later becomes attached to the next succeeding vertebra.

In a few reptiles there is a so-called **proatlas,** consisting of one or two plates lying between the atlas and the skull. It is not known just what relationship this bears to the other vertebrae.

In fin-bearing animals, if the spinal column runs to the end of the body in a straight line (Fig. 405), the caudal fins are known as **diphycercal,** a condition found in the young of all fishes and in adult **cyclostomes, dipnoans,** and **crossopterygians.**

If, as in the elasmobranchs and ganoids, the tail axis bends abruptly upward at the end, but retains the dorsal fin-part and a portion of the ventral region, it forms what is called a **heterocercal tail,** while if there is the same upward bend of the spinal column but the ventral and dorsal fin-portions of the tail become alike as to size and shape, the tail is said to be **homocercal.** Homocercal tails are brought about by the neural arches becoming smaller and the haemal arches becoming larger.

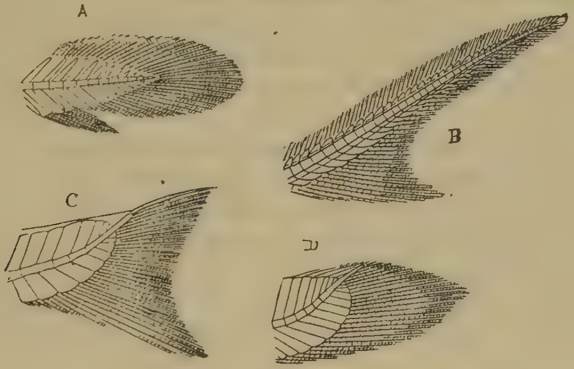


Fig. 405.

Diagrams of the principal forms of tails in fishes. *A*, protocercal fin (as in *polypterus*) ; *B*, heterocercal (as in sharks) ; *C*, homocercal (as in most teleosts) ; *D*, homocercal (as in *Amia*). (After Folsom.)

THE SKULL

Bone either forms in cartilage or membrane and it is quite common to hear biologists speak of cartilaginous and membranous bone. However, recent investigations lead us to believe that the so-called membrane is nothing more or less than cartilage drawn out very thin in those parts where the greatest pressure is produced. This can be understood the better if Figure 406 be carefully studied. It will be noticed that all the superior and inferior boundaries are membranous, for here there is nothing to prevent a considerable extension of growth, while in the innermost portions, where pressure comes from practically all sides, it is cartilage.

Babies have a very soft spot on top of and close to the center of the head for about one and one-half years after birth. Places such as these are called **fontanelles.** These fontanelles are found during the embryonic period at **all spots** in the skull where several points of ossification come together. Ossification begins at many points, each center of ossification extending and growing toward each other. The fontanelle is the unossified spot that constantly becomes smaller until ossification is complete.

Professor Eben J. Carey has recently shown, that contrary to the usually accepted idea that bone grows simply because there is an inner something which makes it assume definite forms, that it is **the stress and** pull and pressure of its location which determines its shape, size, rapidity of growth, and even its joints.

The reason this has not been understood heretofore is because former experimenters took only sections from the growing bone itself for their study, whereas Professor Carey has taken the complete embryological structure, including all muscles and related portions, which might throw light upon the pull and pressure which affects such bone during its growing period.

Observing the ossification centers in the skull will throw light on this subject (Fig. 406). There are many such centers, and they are always found at exactly those points where there is an especial stress or pressure. At these points it may be that sharper bends in the blood vessels cause a slowing of the blood stream, which slowing in turn causes lime salts to be laid down at the angles to a much greater extent than where the blood stream can rush past more swiftly. Then, with each succeeding deposit of such a hardening substance, a still greater number of blood capillaries is affected so that more lime is laid down, and so on, until all of the capillaries have been more or less obliterated and the entire cartilage or membrane has become ossified.

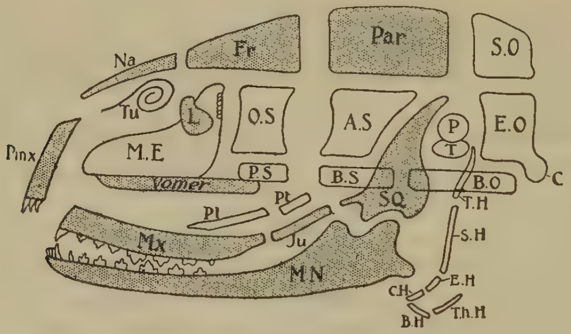


Fig. 406.

A diagram of the skull bones of a mammal, the membrane bones shaded. *BO.*, Basioccipital; *EO.*, exoccipital; *C*, condyle; *SO.*, supraoccipital; *Par.*, parietal; *Fr.*, frontal; *Na*, nasal; *Pmx.*, premaxilla; *ME.*, mesethmoid; *L*, lachrymal; *Tu.*, turbinal; *PS.*, presphenoid; *OC.*, orbitosphenoid; *AS.*, alisphenoid; *BS.*, basisphenoid; *SQ.*, squamosal; *P.*, periotic; *T.*, tympanic; *Pl.*, palatine; *Pt.*, pterygoid; *Mx.*, maxilla; *Ju.*, jugal; *T.H.*, tympanohyal; *S.H.*, stylohyal; *E.H.*, epihyal; *C.H.*, ceratohyal; *B.H.*, basihyal; *Th.H.*, thyrohyal; *vomer*; *MN.*, mandible. (From Borradaile, modified from Flower and Weber.)

Beginning with the axial skeleton, the skull becomes our first object of attention. The **cranium** is that part of it which encloses the brain as well as the bony parts forming the eye-socket, the ear and nose, while the more caudal portion, which is directly connected with the cephalic end of the digestive tract, is called the **visceral skeleton.**

That portion of the skull which is cartilaginous is known as the

chondrocranium, while the membranous portion is called a **membranocranium.**

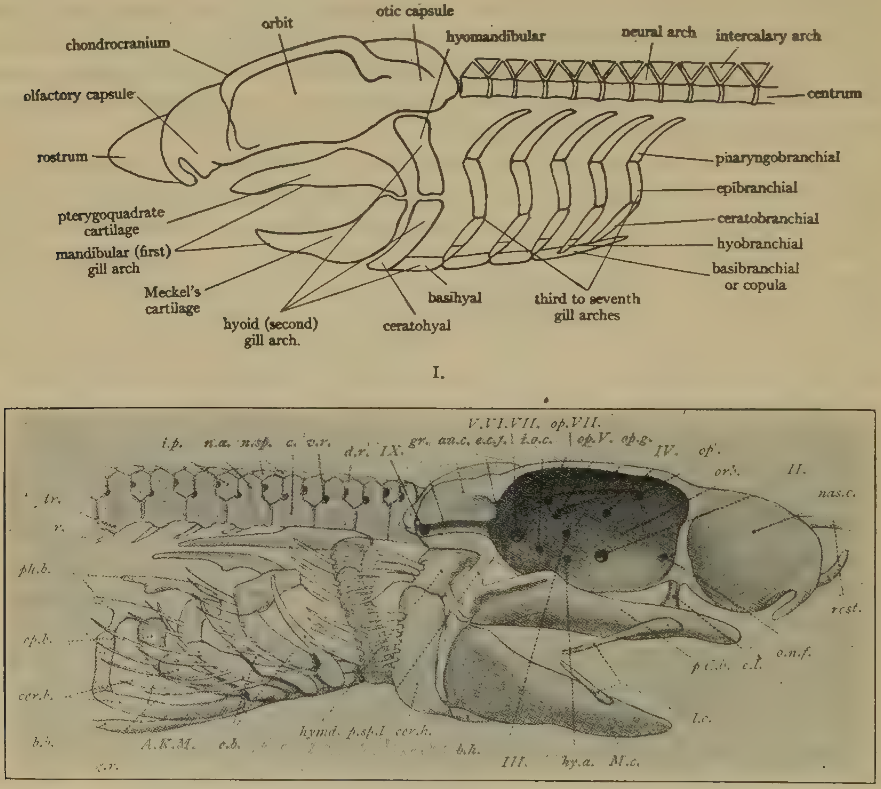
On each side of the notochord (which in the embryo extends as far forward as the infundibulum of the brain) a horizontal plate of cartilage is formed. These plates are known as **parachordal plates** (Figs. 310, 353). These extend laterally to the ears, forward to the end of the notochord, and backward to the exit of the tenth nerve. The **otic capsule** (cartilaginous) then grows about each internal ear and joins the parachordals. This forms a sort of trough in which the most caudal portion of the brain lies. The floor of this trough is known as the **basilar plate,** being formed of the parachordals and notochord as a floor, while the sense capsules constitute the sides.

From this basilar plate two cartilages pass forward on each side forming a similar trough for the anterior part of the brain. According to Professor Kingsley, the lower of these, called the **trabeculae cranii,** "join the anterior margin of the basal plate, while the **dorsal bars,** the **alae temporales** or **alisphenoid** cartilages are eventually connected with the anterior wall of the otic capsules. In most vertebrates the trabeculae and alisphenoids develop as a continuum, but in some elasmobranchs they are at first distinct. The two trabeculae unite in front to form a **median ethmoid plate** beneath the olfactory lobes of the brain, beyond which they diverge as two horns, the **cornua trabeculae,** ventral to the nasal organs. The floor of the trough in front of the ears is formed by the ethmoid plate anteriorly, while behind, it is usually of membrane, but in the elasmobranchs, cartilage gradually extends from one trabecula to the other, closing last below the infundibulum and hypophysis, these lying for a time in an opening **(fenestra,** later **fossa hypophyseos),** and after the closure, in a pocket in the floor of the chondrocranium, one of the cranial landmarks, the **sella turcica.**"

"In the more primitive vertebrates the trough is converted into a tube around the brain by the extension of cartilages between the alisphenoid cartilages and the otic capsules of the two sides dorsal to the brain. This roof or **tegmen cranii** is usually incomplete, having one or more gaps or **fontanelles,** closed only by membrane. In the higher vertebrates the cartilage roof is at most restricted to a mere arch, the **synotic tectum,** between the otic capsules of the two sides.

"Later a pair of nasal capsules develop around the olfactory organs. These are usually fenestrated and become united to the cornua, alisphenoids and ethmoid plate. In a similar way a **sclera** (sclerotic coat) forms around each eye, but since the eye must move, this sense capsule never unites with the rest of the cranium. Behind the otic capsules a varying number of (four in some sharks and most teleosts; in others three; in amphibia two), **occipital vertebrae** are developed, which later fuse with the rest of the chondrocranium. They alternate with myotomes and nerves in this region as do the vertebrae of the vertebral column.

"The cartilaginous **visceral skeleton** arises in the pharyngeal region which is weakened by the presence of the gill clefts. It consists of a series of pairs of bars, the **visceral arches** lying in the septa between the clefts, the bars of a pair being connected below the pharynx. Each bar, at first, is a continuous structure, but to allow for changes of size in the pharynx, each becomes divided into separate parts, while the arches become connected in the mid-ventral line by unpaired elements, the



I.

II.

Fig. 407.

I. Diagram of the chondrocranium vertebral column, and gill arches of an elasmobranch to show particularly the parts and relations of the seven gill arches. (Hyman's modification of Vialleton.)

II. Skull and part of the backbone of a dogfish, seen from the right side. The skeleton of the visceral arches has been pulled a little downwards. *au.c.*, Auditory capsule; *b.b.*, basibranchial cartilage; *b.h.*, basihyal cartilage; *c.*, centrum; *cer.h.*, ceratohyal cartilage; *cer.b.*, ceratobranchial cartilages; *d.r.*,*v.r.*, foramina for the dorsal and ventral roots of a spinal nerve; *e.m.*, extrabranchial cartilages; *e.c.f.*, external carotid foramen; *ep.b.*, epibranchial cartilages; *e.l.*, ethmopalatine ligament; *gr.*, groove for vein which connects orbital and anterior cardinal sinuses; *g.r.*, gill rays; *hy.a.*, foramen for hyoidean artery; *hymd.*, hyomandibular cartilage; *i.o.c.*, interorbital canal; *i.p.*, intercalary plate; *M.c.*, Meckel's cartilage; *l.c.*, labial cartilages; *nas.c.*, nasal capsule; *n.a.*, neural arch; *n.sp.*, neural spine; *o.n.f.*, orbitonasal foramen; *op.V.*, *opVII.*, foramina for ophthalmic branches of fifth and seventh nerves; *op'.*, foramen through which combined ophthalmic nerves pass from the orbit to the snout; *op.g.*, grooves for *op.V.*, *VII.*; *orb.*, orbit; *p.sp.l.*, postspiracular ligament; *pal.b.*, palatine bar; *ph.b.*, pharyngobranchial cartilages; *r.*, rib; *rost.*, rostrum; *tr.*, ventrilateral (so-called transverse) process. (After Borradaile.)

copulae (Fig. 407). The two anterior arches are specialized and have received special names, the first being the **mandibular,** the second the **hyoid arch,** the others, in the region of the functional gills, being called collectively **gill** or **branchial arches.** The number of these last varies with the number of gill clefts, there being seven in the primitive sharks, a smaller number in the higher groups, in which, with the loss of branchial respiration, their form and functions may be altered. At first all are clearly in the head region, but by the unequal growth of cranium

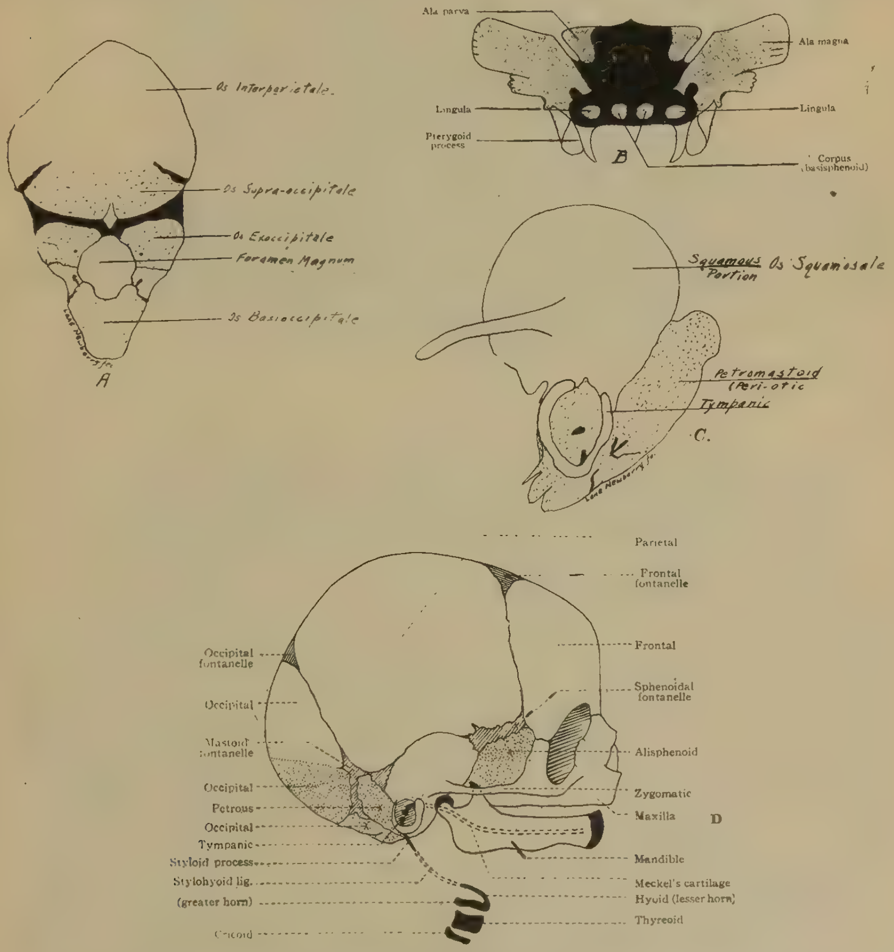


Fig 408.

A, B, C, Bones of early human skull to show their compound nature. *A,* occipital bone at birth showing the five elements of which it is composed. *B,* sphenoid bone in an embryo of four months. *C,* temporal bone at birth, showing its three components. Cartilage represented in black. (Redrawn from Sappey and Hyman.)

D, Diagram of skull of new born child. White areas represent bones of intramembranous origin; dotted areas represent bones (not derived from branchial arches) of intracartilaginous origin; black areas represent derivatives of branchial arches. (Combined from McMurrich and Kollmann.)

and pharynx the gill arches are carried back some distance behind the head. All of the arches are cartilaginous at first."

The mandibular arch lies in the region of the fifth nerve, behind the mouth and between it and the first visceral cleft—the cleft that becomes the spiracle or Eustachian tube. "The arch is divided into dorsal and ventral halves, known respectively as the **pterygoquadrate (palatoquadrate)** and **Meckelian cartilages.** In the elasmobranch and chondrosteous ganoids the pterygoquadrate forms the upper jaw, lying parallel to and joined to the cranium by ligaments or in chimaeroids by continuous growth. With the appearance of bones a new upper jaw is formed, as described below, and the pterygoquadrate becomes more or less reduced, and ossifies as two or more bones with greatly modified functions. Meckel's cartilage is the lower jaw of the lower vertebrates, while in the higher it forms the axis around which the membrane bones of the definitive jaw are arranged.

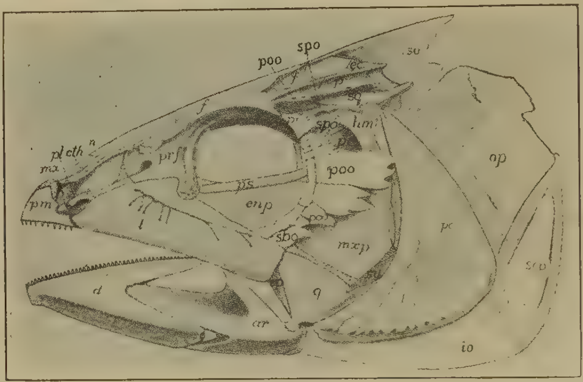


Fig. 409.

Side view of a mackerel. *ar*, articulare; *as*, alisphenoid; *bo*, basioccipital; *d*, dentary; *enp*, entopterygoid; *eo*, exoccipital; *ep*, ectopterygoid; *es*, extrascapular; *epo*, epiotic; *f*, frontal; *io*, interopercular; *eth*, ethmoid; *l*, lacrimal; *mx*, maxillary; *mxp*, metapterygoid; *n*, nasal; *op*, opercular; *p*, parietal; *pe*, petrosal; *pf*, postfrontal; *pl*, palatine; *pm*, premaxillary; *po*, preoperculum; *poo*, postorbital; *prf*, prefrontal; *ps*, parasphenoid; *q*, quadrate; *sbo*, suborbital; *so*, supraoccipital; *sop*, suboperculum; *spo*, sphenotic; *sq*, squamosal; *ssc*, suprascapular; *sy*, symplectic. (From Kingsley after Allis.)

"The hyoid arch lies between the spiracle and the first true gill cleft, in the region of the seventh nerve. It divides into an upper element, the **hyomandibular cartilage**, and a ventral portion, the hyoid proper, which may subdivide into several parts. In the lower elasmobranchs the hyomandibular and the rest of the hyoid arch are closely connected, but in the higher fishes the hyomandibular becomes more separated from the ventral portion and tends to intervene between the mandibular arch and the cranium, becoming a **suspensor** of the jaws. Still higher it loses its suspensorial functions, becomes greatly reduced, and apparently is

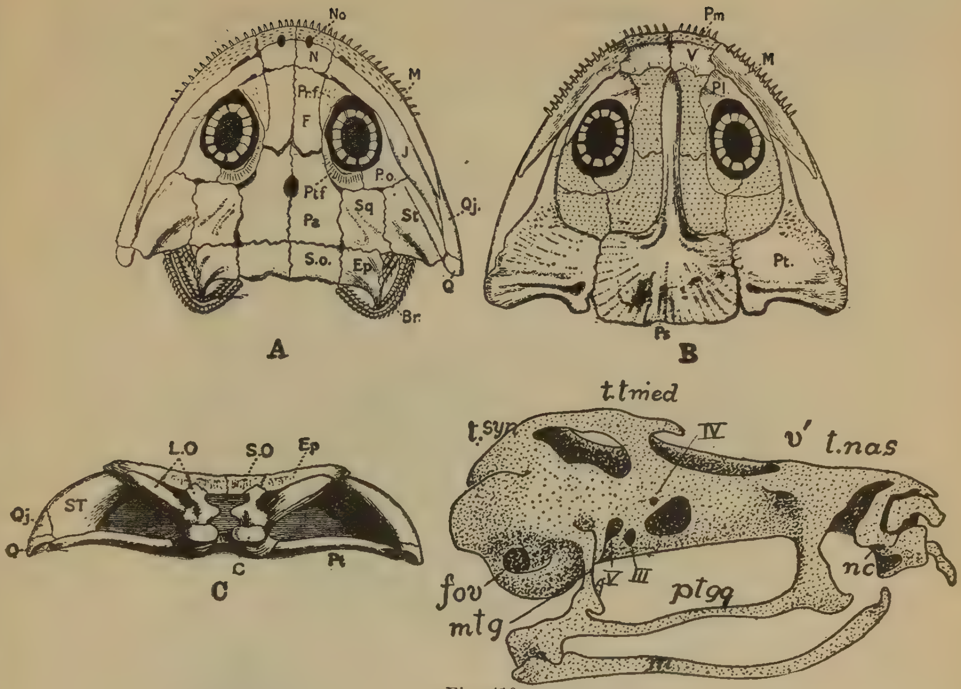


Fig. 410.

A, Dorsal and *B*, Ventral views of cranium of *Branchiosaurus salamandroides*, *C*, Posterior view of cranium of *Trematosaurus*. *Br*, branchial arches; *C*, condyle; *Ep*, epiotic; *F*, frontal; *J*, Jugal; *L.O*, lateral occipital; *M*, maxillary; *N*, nasal; *No*, nostril; *Pa*, parietal; *Pl*, palatine; *Pm*, premaxillary; *P.o*, postorbital; *Pr.f*, prefrontal; *Pa*, parasphenoid; *Pt*, pterygoid; *Ptf*, postfrontal; *Q*, quadrate; *Qj*, quadrato-jugal; *S.o*, supraoccipital; *Sq*, squamosal; *St*, Supratemporal; *V*, vomer. (After Gadow.)

D, Chondrocranium of a frog shortly after metamorphosis. *fov*, fenestra vestibuli; *m*, Meckel's cartilage; *mtg*, metapterygoid; *nc*, nasal capsule; *ptgq*, pterygoquadrate; *tnas*, tectum nasalis; *tsyn*, tectum synoticum; *ttmed*, taenia tecti medialis; *III-V*, nerve exits. (From Kingsley after Gaupp.)

subsidiary to the sense of hearing or it may be lost, the question not being decided. The hyoid proper becomes more or less intimately connected with the arches behind and also is largely concerned in affording a support for the tongue.

"The branchial arches are all similar to each other in the lower vertebrates, but with the loss of branchial respiration in the higher groups, they tend to become reduced, the reduction beginning behind. Some may entirely disappear, others give rise to the laryngeal cartilages and the first may fuse with the hyoid. The first arch is in the region of the ninth nerve; the others in that supplied by the tenth."

*Here it will be necessary to review the frog skull very thoroughly, bearing in mind that, as in all vertebrates, the **occipitals**, the **two sets of**

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*The frog does not have all the bones mentioned. All head bones that any vertebrate possesses are given in the list, so that the student must not expect to find any animal with all these structures, though he will find no vertebrate with head-bones not mentioned here.

sphenoids, and the **ethmoids,** are the four groups constituting the cartilaginous cranium. (Compare Figs. 407, 409, 410, 411, 412, 413, 414.)

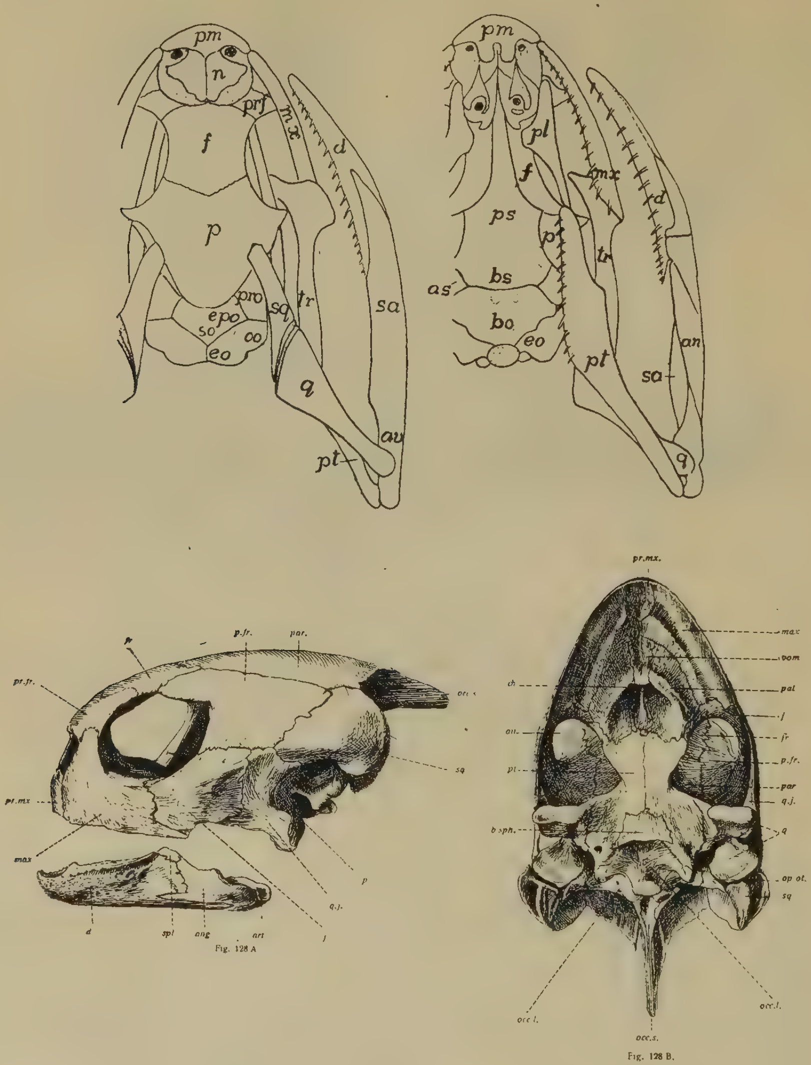


Fig. 411.

Upper two views, skull of snake. *an*, angulare; *av*, articular; *bo*, basioccipital; *bs*, basisphenoid; *d*, dentary; *eo*, exoccipital; *epo*, epiotic; *f*, frontal; *mx*, maxillary; *n*, nasal; *oo*, opisthotic; *p*, parietal; *pl*, palatine; *pm*, premaxillary; *pro*, prootic; *ps*, parasphenoid; *pt*, pterygoid; *q*, quadrate; *sa*, surangulare; *so*, supraoccipital, *sq*, squamosal; *tr*, transversum. (From Kingsley after W. K. Parker.)

Lower two views, skull of turtle. *A*, lateral view. *B*, from below. *ang.* angulare, *art*, articulare; *au*, orbit; *b.sph.*, basisphenoid; *ch*, choanae; *d*, dentary; *fr*, frontal; *j*, jugular; *max*, maxillae; *occ.b*, basi-occipital; *occ.l.*, lateral occipital; *occ.s.*, superior occipital; *op.ot.*, opisthotic; *pal*, palatine; *par*, parietal; *p.fr.*, postfrontal; *pr.mx.*, premaxillae; *pr.fr.*, prefrontal; *pt*, pterygoid; *q*, quadrate; *q.j.*, quadratojugal; *sq*, squamosal; *vom*, vomer. (After Schimkewitsch.)

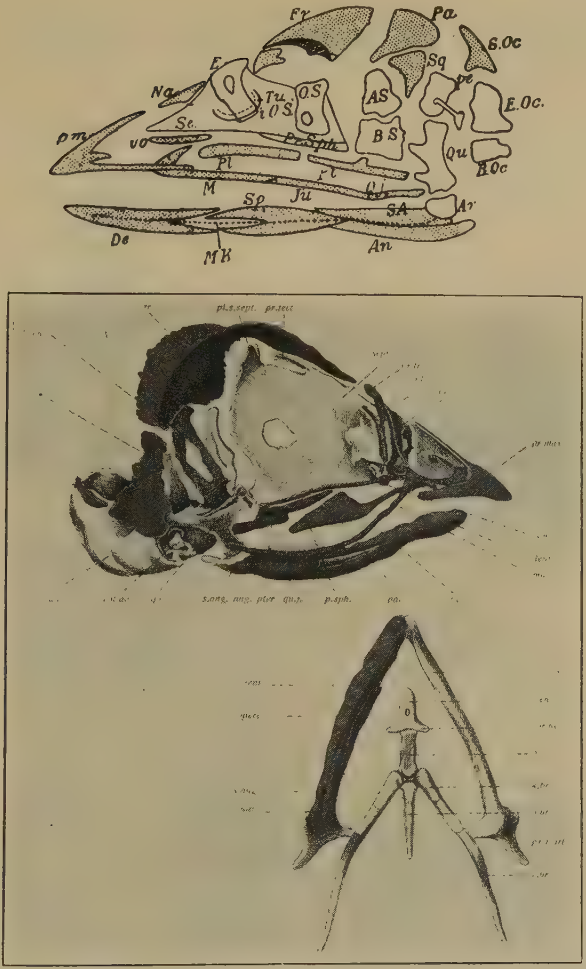


Fig. 412.

Upper view, a diagram of a bird's skull, disarticulated. (After Gadow.) Membrane bones shaded. *B.Oc.*, basioccipital; *E.Oc.*, exoccipital; *S.Oc.*, supraoccipital; *Pa.*, parietal; *Fr.*, frontal; *Na.*, nasal; *pm.*, premaxilla; *M.*, maxilla; *Ju.*, jugal; *Qj.*, quadrato-jugal; *Qu.*, quadrate; *Pl.*, palatine; *Pt.*, pterygoid; *pe.*, periotic; *Sq.*, squamosal; *AS.*, alisphenoid; *B.S.*, basisphenoid; *O.S.*, orbitosphenoid; *Pr.Sph.*, presphenoid; *vo.*, vomer; *iOS.*, interorbital septum; *E.*, ethmoid; *Se.*, nasal septum; *De.*, dentary; *Sp.*, splenial; *An.*, angular; *SA.*, supra-angular; *Ar.*, articular; *MK.*, Meckel's cartilage.

Lower views, model of developing chick-skull. *A*, profile view, and *B*, hyoid apparatus, as seen from below. *ang.*, Angulare; *b.br.*, basibranchial; *b.hy.*, basihyal; *c.aud.*, auditory (otic) capsule; *c.ent.*, entoglossal cartilage; *c.meck.*, Meckel's cartilage; *col.au.*, auditory columella; *cor.hy.*, cornua of the hyoid; *dent*, dentary; *e.br.*, epibranchial, *1*; *fr*, frontal; *k.br*^{1}., ceratobranchial, *1*; *max*, maxillary; *nas*, nasal; *operc*, opercular; *pa*, parietal; *pal*, palatine; *pl.a.o.*, anteorbital plane; *pl.s.sept.*, supraseptal plane; *pl.sph.l.*, sphenolateral plane; *pr.fr.*, prefrontal; *pr.r.art.*, retroarticular process; *pr.tect.*, Processus tectalis (roof-forming); *p.sph.*, parasphenoid; *pter*, pterygoid; *qu*, quadrate; *qu.j.*, quadrato-jugal; *s.ang.*, supraangular; *sept.i.o.*, interorbital septum; *sq*, squamosal; *vom*, vomer; *zyg*, zygomatic process. (After Gaupp.)

The **occipital** is divided into:

A **supraoccipital**, an **exoccipital** on each side, and a **basioccipital.** These four bones form the borders of the **foramen magnum.**

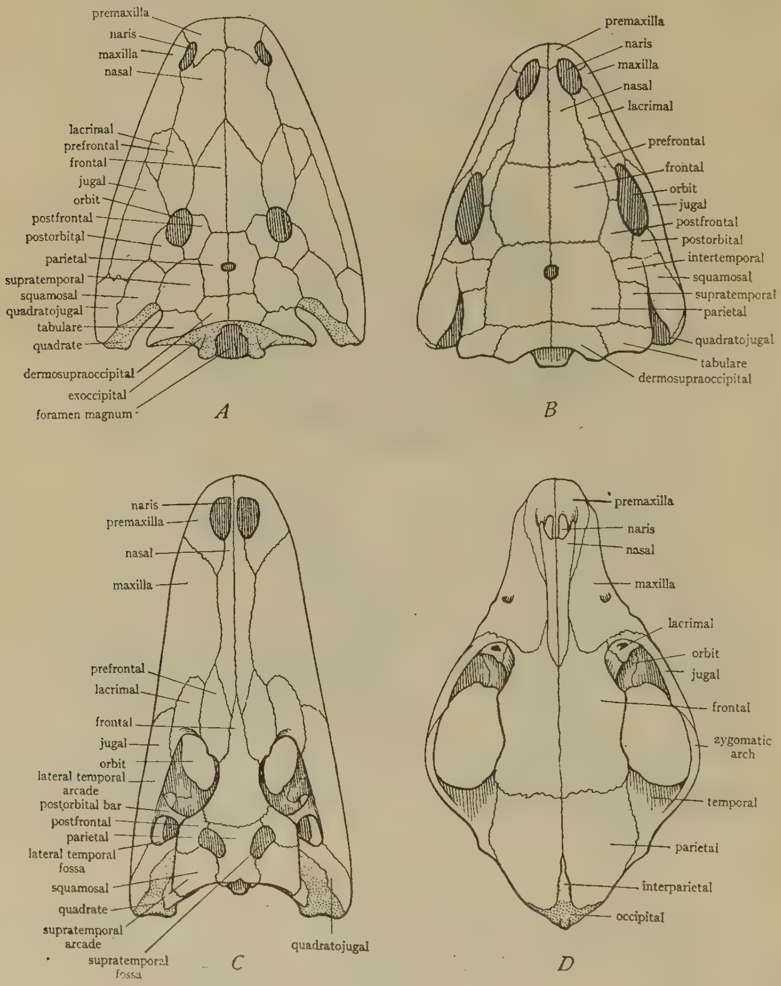


Fig. 413.

Dorsal view of the skulls of four representative vertebrates to show changes and reduction of the membrane bones of the roof. *A*, skull of an extinct amphibian, *Capitosaurus*, belonging to the *Stegocephala;* note the large number of membrane bones completely roofing the skull. *B*, skull of one of the most ancient reptiles, *Seymouria*, belonging to the *Cotylosauria;* the membrane bones are nearly as numerous as in the amphibian, are similarly arranged, and completely roof the skull. *C*, skull of a modern reptile, the alligator; several of the membrane bones which were present in the extinct forms have been lost, and the roof has several openings. *D*, skull of a modern mammal, the dog, showing still greater loss of membrane bones. Membrane bones blank; cartilage bones stippled. (From Hyman's "A Laboratory Manual for Comparative Vertebrate Anatomy," *A*, after Reynolds, *B*, after Williston, by permission of the Chicago University Press.)

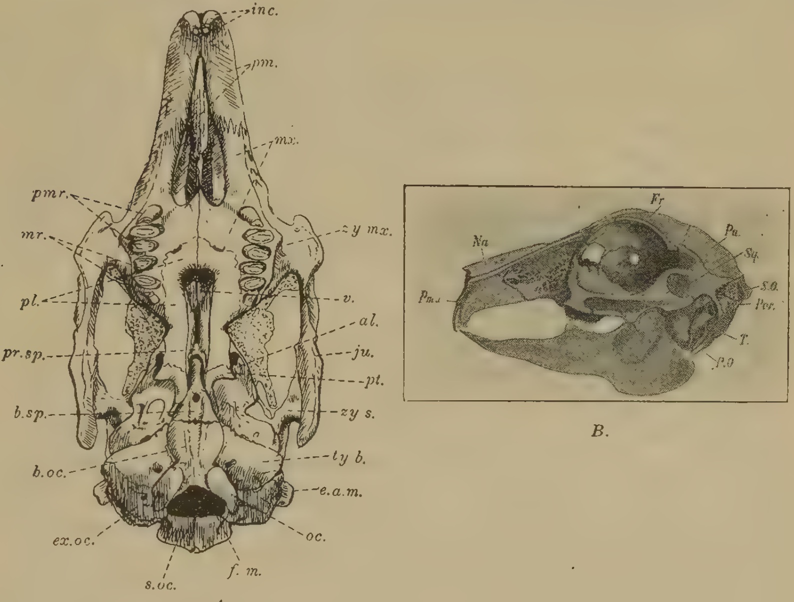
The **sphenoids** are:

The **basisphenoid,** extending forward to the sella turcica.

The **presphenoid,** extending from the trabeculae to the ethmoid plate.

The **alisphenoid,** closely related to the basisphenoid.

The **orbitosphenoid,** in close relation with the presphenoid.



A. *B.*

Fig. 414.

A, A ventral view of the skull of a rabbit. *al.*, External process of the alisphenoid; *b.oc.*, basioccipital; *b.sp.*, basisphenoid; *e.a.m.*, external auditory meatus; *ex.oc.*, exoccipital; *f.m.*, foramen magnum; *inc.*, incisors; *ju.*, jugal; *mr.*, molars; *m.x.*, maxilla; *oc.*, occipital condyle; *pl.*, palatine; *pm.*, premaxilla; *pmr.*, premolars; *pr.sp.*, presphenoid; *pt.*, pterygoid; *s.oc.*, supraoccipital; *ty.b.*, tympanic bulla; *v*, vomer; *zy.mx.*, zygomatic process of maxilla; *zy.s.*, zygomatic process of squamosal. (From Borradaile.)

B, A side view of a rabbit's skull. *Pmx.*, Premaxilla; *Na.*, nasal; *Fr.*, frontal; *Pa.*, parietal; *Sq.*, squamosal; *S.O.*, supraoccipital; *Per.*, periotic; *T.*, tympanic (the reference line points to the bony external auditory meatus, beneath it lies the inflated bulla); *PO.*, paroccipital process. (From Thomson.)

The **ethmoids** are divided as follows:

Mesethmoid, lying medially.

Ectethmoid, one on each side of the mesethmoid.

The **ectethmoid** becomes the ectethmoid labyrinth which comes to lie between ectethmoid and mesethmoid, and the **turbinate** bones are sometimes added here.

From the **otic capsule** are developed various otic or **petrosal bones.** These are usually divided into:

Prootic, lying in front of the ear.

Opisthotic, lying behind, although usually meeting below with a

Epiotic and a **sphenotic,** in the teleosts and a few other forms developed from the lateral wall of the otic capsule and lying in front and

Pterotic, lying behind and directly above the horizontal semicircular canal of the ear.

The otic bones usually fuse and form a **petrosal bone** in all the higher forms. This lies directly between the lateral parts of the basioccipital and the sphenoid.

A ring of sclerotic bones is often formed from the sclera of the eye of birds and reptiles, though these never unite with the regular bones. From the nasal capsules a **lateral ethmoid** often forms on the upper wall, while the **turbinate bones** form on the medial and lateral walls. In man the single occipital bone is formed by the four occipitals mentioned above. The single sphenoid is a fusion of the six sphenoids mentioned above, the **alisphenoids** form the greater wings and the **orbito sphenoids** the lesser ones. (Fig. 408.) The ethmoid is similarly made up of the various ethmoids mentioned.

The **membranocranium** gives rise to the following bones:

Nasal, covering the olfactory region.

Frontals, between the orbits.

Parietals, on the same level with the otic capsules.

Inter-parietal, unpaired, between parietal and supraocciptal.

While these are practically all of the membranocranial bones in the roof of the cranium of the higher forms, others may appear in the lower groups. For example:

Supratemporal, lying lateral to each parietal.

Postfrontal, behind the orbit.

Postorbital, forming the posterior wall of the orbit.

Supraorbital, taking the place of the frontal in forming the superior or medial wall of the orbit.

Prefrontal, bounding the orbit in front.

Lacrimal, lying lateral to the prefrontal.

Intertemporal, lying dorsal or medial to the alisphenoid.

Postparietal, between parietals and interparietals.

Epiotic, lying above each otic capsule and usually called the **tabulare.**

If as in some of the fish, birds, and reptiles, the basilar plate and trabeculae fail to ossify, then the roof of the mouth, which is also, of course, the frontal of the cranium, is also a membrane bone called the **parasphenoid,** while farther forward the **vomers** or **plough-share bones** are also membranous and lie in the nasal region. Both parasphenoid and vomers may bear teeth.

As soon as bone commences to form, the **pterygoquadrate** changes considerably, becoming closely connected with the cranium in front. The middle portion disappears and the **palatines,** a pair of membrane bones, replace the disappearing part. The remaining portion of the visceral arch ossifies, usually though not always, forming two bones on each side, the paired **anterior pterygoid** and the paired **posterior quadrate.** These now become the **suspensor** of the lower jaw. In some forms such as the teleosts and the reptiles, there appears an entire series of pterygoid bones.

Outside of the pterygoquadrate a second arch of membrane bone develops to form the functional upper-jaw in all bony vertebrates. This when fully developed consists of:

Squamosal, underlying the quadrate.

Quadratojugal, which follows immediately.

Zygomatic, also called **malar** or **jugal.**

Maxillary.

Premaxillary, which forms the tip of the jaw.

Only the maxillary and premaxillary bear teeth.

When, as in the higher forms of human life, the roof of the skull is not continuous, but openings of various kinds are seen, such openings are known as **fossae.** The more common and constant are as follows:

Infratemporal, being the most lateral.

Supratemporal, which is separated from the foregoing by the **squamoso-postorbital bars.**

Posttemporal, lying between the parietal, supratemporal, and occipital bones.

Temporal, when infra and supra temporal fossae unite.

Any of the bones mentioned above may fuse or disappear entirely in certain groups, while in others there may be connections quite different from the usual type.

The lower jaw is by no means modified as extensively as the upper. **Meckel's cartilage,** by an ossification, gives rise to two bones in each half of the lower jaw. There is an **articular bone (articulare)** where the jaw meets with the quadrate, and at the tip where both sides unite—the **symphysis**—there may be a **mento-Meckelian** bone, although this does not occur often. The rest of Meckel's cartilage forms an axis about which the membrane bones of the lower jaw are arranged. These are as follows:

(1) **Dentary,** surrounding the Meckelian in front and bearing teeth.

(2) **Splenial,** on the inner side behind the dentary and often bearing teeth.

(3) **Angulare,** on the lower side usually extending back to the hinder end of the jaw.

(4) **Surangulare,** lying on the outer posterior part of the jaw.

(5) **Coronoid,** on the upper side attach the muscles which close the jaws.

(6) **Goniale,** also called **antarticular** or **dermarticulare,** lies on the medial and ventral sides of the articulare with which it usually fuses.

The dentary, splenial, and angulare are usually found, but very few vertebrates have them all.

In the hyoid and branchial arches the outside portions are known by the same names as the corresponding cartilages, membrane bones never being found here.

The method by which the jaws are suspended varies. If the pterygoquadrate is directly connected with the cranium as in a few elasmobranchs, the suspension is called **amphistylic.** If it is held in place by ligaments and the hyomandibular is interposed between the otic capsule and the hinder end of the jaw, it is called **hyostylic,** while, if the pterygoquadrate is more or less fused with the cranium, as in all the higher forms beyond the fishes, it is known as **autostylic.**

THE APPENDICULAR SKELETON

There are two types of appendages, namely: **median** or **azygos,** which are found in aquatic vertebrates, and the regular **paired** appendages found in all other classes except the cyclostomes. Several theories have been advanced to account for the two types. One of these is that the two types of appendages have no relation to each other, and developed independently, the pelvic and pectoral girdles being supposed to have originated from the gill arches, while the appendage bones have been derived from that portion which normally supports the gills. The other view assumes that two longitudinal folds ran the full length of the body behind the head (Fig. 415), each of these folds being supported by a series of skeletal rods. The two dorsal and two ventral folds then fused to form the dorsal and ventral fin. The anal opening is, however, on the ventral side. Consequently, the caudal fins had to be formed from the ventral fusion **behind** the anal opening, while the portion anterior to the anal opening develops into the appendages proper.

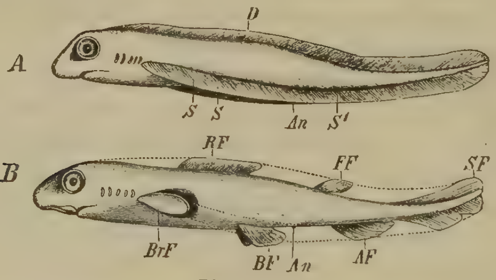


Fig. 415.

Diagrams showing *A*, the undifferentiated condition of the paired and unpaired fins in the embryo, and *B*, the manner in which the permanent fins are formed from the continuous folds. *AF*, anal fin; *An*, anus; *BF*, pelvic fin; *BrF*, pectoral fin; *D*, dorsal fin-fold; *FF*, dorsal fin; *RF*, dorsal fin; *SF*, tail-fin; *S*, *S*, lateral folds which unite at *S'* to form ventral fold. (From Wiedersheim.)

Both theories are unsatisfactory, the latter because there is no double origin of the dorsal fins, and the former, known as the **gill-arch-theory,** is unsatisfactory due to the fact that the paired appendages develop **outside the body musculature,** while the visceral arches are always internal.

All median appendages have the form of fins, and are termed **dorsal, terminal** (caudal), or **ventral** (anal). They may occur as a continuous fin, or they may be broken up with intervals between. Fins occur in all fishes, in the larval and tailed amphibians, and even in rather isolated groups, such as the **Ichthyosaurs** and the whales, although in the amphibians and the higher groups, there is no skeleton in the median fins.

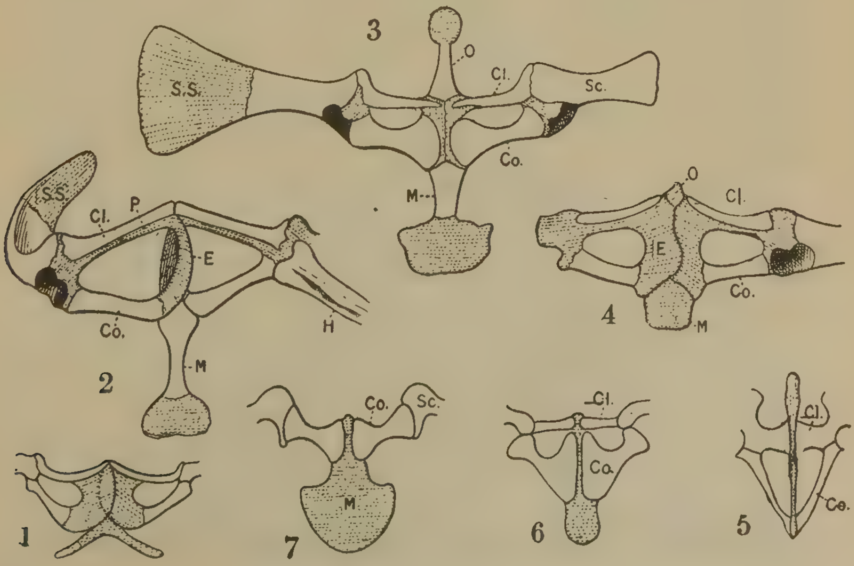
The skeleton of the fins usually consists of definite metameric cartilaginous or osseous bars, each of which is divided into a proximal **basale** and a distal **radiale.** The basale often articulates or alternates with the spinous processes of the vertebrae. The radiale supports the fins proper.

In the higher forms of vertebrates, when the skeleton of the fins is not composed of cartilage or bone, there is a horny substance known as **elastoidin** which forms of a number of slender rods in greater number than the somites. They arise from the corium just below the epidermis, often being united in bundles, and thus form soft-finned rays, often replacing the radiale.

PAIRED APPENDAGES

An extinct shark had a pair of fins approximately in the region where pectoral and pelvic girdles normally form, but no satisfactory theory has yet developed as to how arms and legs were derived from this type of fin.

I.



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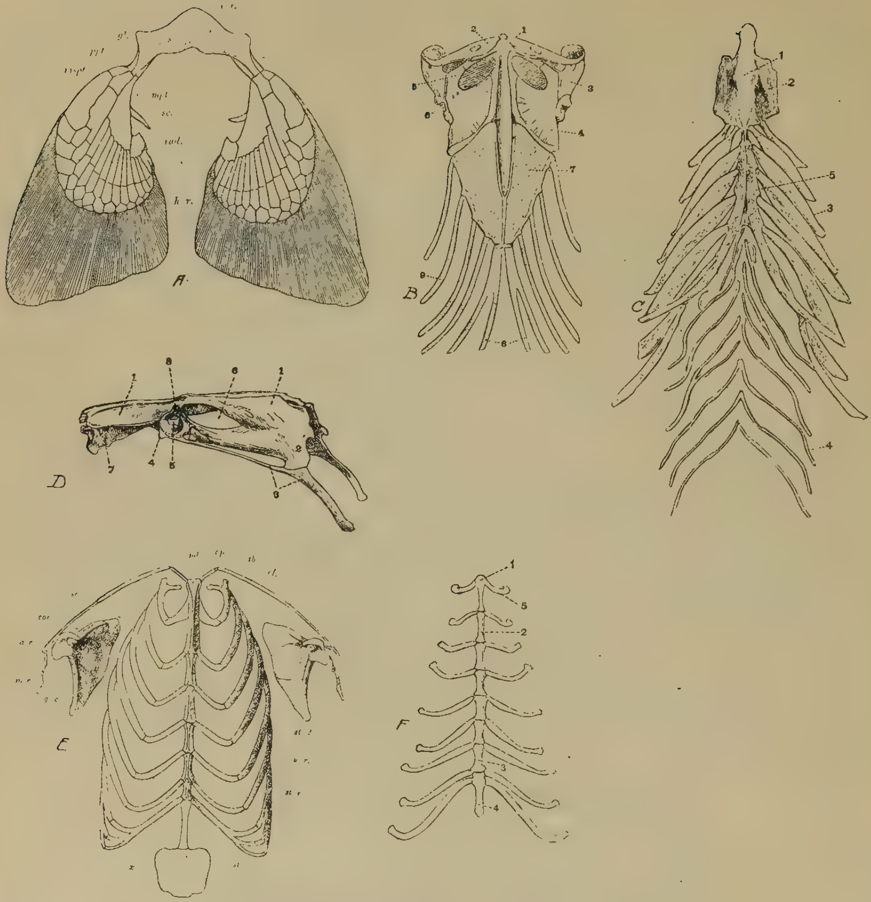

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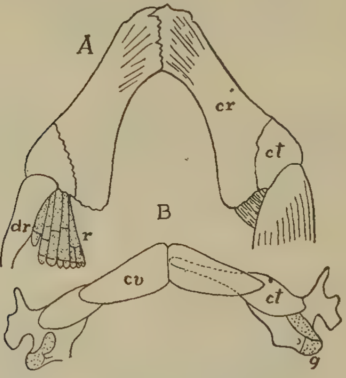

Fig. 416.

Shoulder girdles. I. Ventral views of the shoulder girdles of various Anura. (Slightly enlarged.) 1, *Bombinator igneus* (a species of Frog) and 2, *Bufo vul-*

The internal support of both shoulder and pelvic girdle consists of inverted arches across the ventral side of the body, the limbs of the arch extending dorsally. The part to which the limbs are attached is called the girdle. The arch itself always forms in cartilage, though membrane bone or dermal bone may be added.

The typical girdle consists of three elementary parts, one dorsal and two ventral, all of which meet at the point of attachment of the limbs, and all contribute to form the socket, in the forelimb called the **glenoid,** and in the hindlimb known as the **acetabulum,** and shows why we consider pectoral and pelvic girdles and appendages homologues.

THE SHOULDER GIRDLE (Fig. 416)

In fishes, the shoulder girdle is more or less U-shaped, with the glenoid fossa at the dorsal end, and immediately dorsal to the fossa lies the scapular region. Quite often, the dorsal part of the scapular region is again divided, so that a supra-scapula is formed. In the skates the supra-scapula articulates with the adjacent vertebrae; usually, however, the entire girdle lies free from the axial skeleton. A pair of clavicles form from the skin. These overlay the **coracoid** region of the girdle, and meet in the midline, while a **cleithrum,** a second bone above the glenoid fossa, forms. In some of the ganoids, it is the cleithrum which extends toward the midline so as to take the strain; in fact, it is assumed that in higher groups, where the two halves of the cartilaginous girdle have separated, the separation is due to the stress laid upon these parts.

In the higher ganoids and in the teleosts, the cleithrum increases in

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garis (Toad) as examples of the arciferous type. 3, Adult, and 4, metamorphosing Frog, *Rana temporaria* showing change from the arciferous into the firmisternal type. 5, *Hemisus guttatum* (narrow-mouthed toad). 6, *Breviceps gibbosus* (tailless amphibia). 7, *Cacopus systoma* (narrow-mouthed toad). Cartilaginous parts are dotted. Ossified parts are white. *Cl,* clavicle; *Co,* coracoid; *E,* epicoracoidal cartilage; *H,* humerus, *M,* metasternum; *O,* omosternum; *P,* precoracoid; *Sc,* scapula; *S.S,* suprascapula. (From Gadow and Boulenger.)

II. *A,* The skeleton of the pectoral fins and girdle of a dogfish, seen from the ventral side. (After Borradaile.) *cor.,* Coracoid region; *gl.,* glenoid surface; *h.r.,* horny rays; *mpt.,* metapterygium; *mspt.,* mesopterygium; *ppt.,* propterygium; *rad.,* cartilaginous rays; *sc.,* scapula. *B.* Ventral view of the shoulder-girdle and sternum of a Lizard, *Loemanctus longipes.* (After Parker.) 1. Interclavicle. 2. Clavicle. 3. Scapula. 4. Coracoid. 5. Precoracoidal process. 6. Glenoid cavity. 7. Sternum. 8. Sternal bands not united. 9. Sternal rib. *C.* Sternum and associated membrane bones of a Crocodile, *C. palustris.* (After Shipley and MacBride.) The last pair of abdominal ribs which are united with the epipubes by a plate of cartilage have been omitted. 1. Interclavicle. 2. Sternum. 3. Sternal rib. 4. Abdominal splint rib. 5. Sternal band. *D.* Lateral view of the pelvis and sacrum of a Duck, *Anas boschas* (After Shipley and MacBride.) 1. Ilium. 2. Ischium. 3. Pubis. 4. Pectineal process, the rudiment of the prepubis corresponding to the pubis of the Lizard. 5. Acetabulum. 6. Ilio-ischiatic foramen. 7. Fused vertebrae. 8. Facet on which the projection on the femur, the trochanter, plays. *E,* The breastbone and shoulder girdle of a rabbit, seen from below and somewhat from in front. (After Borradaile). *acr.,* Acromion; *cl.,* clavicle; *cor.,* coracoid process; *cp.,* capitulum; *g.c.,* glenoid cavity; *mb.,* manubrium; *mcr.,* metacromion; *sc.,* scapula; *st.r.,* sternal portion of a rib; *st.* 2, *st.*6, second and sixth sternebræ; *tb.,* tuberculum; *v.r.,* vertebral portion of a rib; *x.,* xiphisternum; *x.c.,* xiphoid cartilage. *F.* Sternum and sternal ribs of a Dog, *Canis familiaris.* (After Shipley and MacBride.) 1. Presternum. 2. First sternebra of mesosternum. 3. Last sternebra of mesosternum. 4. Xiphisternum. The flattened cartilaginous plate terminating the xiphisternum is not shown. 5. First sternal rib.

III. Pectoral girdles of two types of ganoids. *A, Acipenser* (Sturgeon) and *B, Polypterus* (African ganoid). *ct,* cleithrum; *cv,* clavicula; *dr,* dermal rays; *g,* glenoid surface; *r,* cartilaginous radialia. (From Kingsley after Gegenbaur.)

size and usurps the function of the clavicle, while the clavicles themselves disappear.

Other bones from the skin may develop, such as the **supracleithra** (post-temporals or supra-temporals). These connect the girdle with the skull; sometimes also post-clavicles and infra-clavicles develop.

A review of the appendicular skeleton, as formed embryologically in the chick and frog, will give one a good idea of the parts as they appear in amphibia. In the reptiles, there is a considerable variation in the shoulder girdle. In the turtle, its position inside the carapace and internal to the ribs is supposed to be due to the fact that the girdle begins its development in front of the ribs, and later sinks to the position it is to occupy in adult life. The scapula, procoracoid, and coracoid, are well developed. The median ends of the latter are connected by a cartilaginous epicoracoid. In

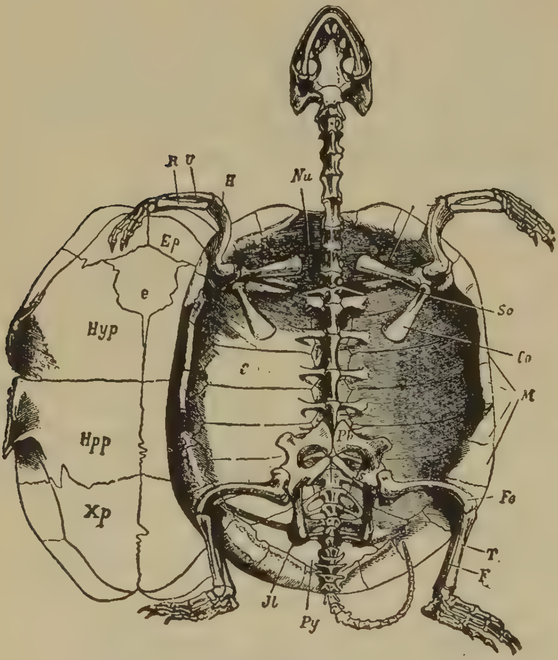
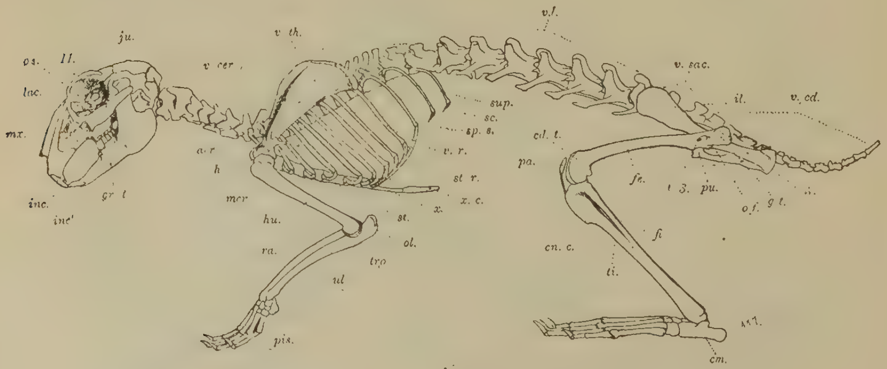


Fig. 417.

Tortoise skeleton *Cistudo lutaria*. Ventral side with plastron removed and placed at one side. *C*, costal plate; *Co*, coracoid; *e*, endoplastron; *ep*, epiplastron (clavicle); *F*, fibula; *Fe*, femur; *H*, humerus; *Hyp*, hyoplastron; *Hpp*, hypoplastron; *Il*, ilium; *Js*, ischium; *M*, marginal plates; *Nu*, nuchal plates; *Py*, pygal plates; *R*, radius; *sc*, scapula; *T*, tibia; *U*, ulna; *Xp*, xiphiplastron. (From Parker and Haswell after Zittel).



A.

other forms of reptiles, the procoracoid usually is reduced, and the clavicle takes its place, though in the lizards, the procoracoid still remains in its reduced condition. Clavicles may or may not be present in turtles. If they are, they are represented by the **epiplastron** (Fig. 417), which is an element of the carapace. In the chameleons and crocodiles

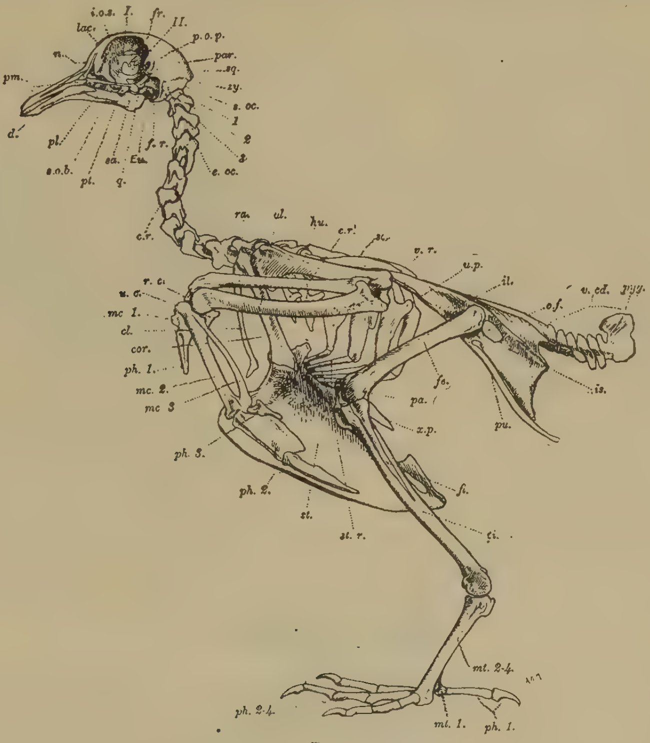


Fig. 418. A.—The skeleton of a rabbit.

acr., Acromion; *cd.t.*, condyles for tibia; *cm.*, calcaneus; *cn.c.*, cnemial crest; *fe.*, shaft of femur; *fi.*, fibula; *g. t.*, great trochanter; *gr.t.*, premolar and molar teeth; *h.*, head of humerus, fitting into glenoid cavity; *hu*, shaft of humerus; *il.*, ilium; *inc.*, upper incisor teeth of the left side; *ind.*, lower incisor tooth; *is.*, ischium; *ju.*, jugal bone; *lac.*, lacrymal bone; *mcr.*, metacromion; *mx.*, maxilla; *o.f.*, obturator foramen; *ol.*, olecranon process; *os.*, orbitosphenoid bone; *pa.*, kneecap; *pis.*, pisiform bone; *pu.*, pubis; *ra.*, radius; *sc.*, scapula; *sp.s.*, spine of scapula; *st.*, sternum; *st.r.*, sternal ribs; *sup.*, suprascapula; *t.*3, third trochanter; *ti.*, tibia; *tro.*, trochlea; *ul.* ulna; *v.cd.*, *v.cer.*, *v.l.*, *v.sac.*, *v.th.*, caudal, cervical, lumbar, sacral, and thoracic regions of the backbone; *v.r.*, vertebral ribs; *x.*, xiphisternum; *x.c.*, xiphoid cartilage; *II*, foramen for optic nerve. The clavicle and hyoid are not shown.

B.—The skeleton of a pigeon, seen from the left side.

c.r., Fixed cervical rib; *c.r*¹., free cervical ribs; *cl.*, clavicle; *cor.*, coracoid; *d.*, dentary; *Eu.*, Eustachian tube; *e.oc.*, exoccipital; *f.r.*, fenestral recess; *fe.*, femur; *fi.*, fibula; *fr.*, frontal; *hu.*, humerus; *i.o.s.*, interorbital septum; *il.*, ilium; *is.*, ischium; *lac.*, lacrymal; *mc.* 1-3, metacarpals; *mt.* 1-4, metatarsals; *n.*, nasal; *o.f.*, obturator foramen; *pa.*, patella; *par.*, parietal; *ph.* 1-4, phalanges; *pl.*, palatine; *pm.*, premaxilla; *p.c.p.*, postorbital process of frontal; *pt.*, pterygoid; *pu.*, pubis; *pyg.*, pygostyle; *q.*, quadrate; *r.c.*, radial carpal; *ra.*, radius; *s.o.b.*, suborbital bar; *s.oc.*, supraoccipital; *sa.*, supra-angular; *sc.*, scapula; *sq.*, squamosal; *st.*, sternum; *st.r.*, sternal ribs; *ti.*, tibia; *u.c.*, ulnar carpal; *u.p.*, uncinate process; *ul.*, ulna; *v.cd.*, caudal vertebræ; *v.r.*, vertebral rib; *x.p.*, xiphoid process; *zy.*, zygomatic process of the squamosal; *I.*, *II.*, foramina for first two cranial nerves; 1-3, first three cervical vertebræ. (From Borradaile).

the clavicle is entirely lost. In limbless lizards, the girdles are greatly reduced, and in fact in the **Ophidians** the girdle itself has completely vanished.

In birds (Fig. 418), the scapula is formed as a sword-shaped bar overlying the ribs, while the coracoid extends from the glenoid fossa to the anterior end of the sternum. The procoracoid has entirely disappeared. The two clavicles unite ventrally to form the **wishbone, called the furcula** (Fig. 418, B.cl.). This may either articulate with the sternum or lie free.

In the monotremes the shoulder girdle is quite like that of the lizard. This is also true of the young marsupials, but in the adult it becomes quite like that in all other adult mammals. The coracoid in this instance is reduced to the small coracoid process, definitely ankylosed to the ventral end of the scapula. The scapula is well developed, forming a crest called the **spina scapulae** on its external surface, which in turn culminates in an **acromion process** (Fig. 416, II, E, acr.). The clavicle varies with the manner in which the limb is used.

In the higher forms of mammals, the clavicle serves as a strong brace between shoulder and sternum. However, in the ungulates, in the whales, and in a few carnivores it has entirely disappeared. In some mammals it appears as a mere rudiment, without apparent functional value.

Two small, cartilaginous elements often intervene between clavicle and sternum, called **episternalia,** or **suprasternalia.** Their homologies are unknown.

THE HIP GIRDLE

The hip or pelvic girdle (Fig. 419) is quite homologous to the shoulder girdle, the **acetabulum** representing the glenoid fossa. The **ilium** represents the scapula, while **pubis** and **ischium** represent the procoracoid and coracoid. The gap or open space between pubis and ischium is known as the ischio-pubic fenestra. In the lower forms there is another opening, called the obturator foramen, through which the obturator nerve passes to the pelvis. In the higher forms, this usually unites with the ischio-pubic fenestra, the entire opening then being called the **obturator foramen.**

In the lower forms, such as the fishes, the basalia are on the inside, and fused to form a single basal, through which the obturator nerve may pass. The radialia are on its distal surface. The basalia of the two sides do not meet, though there is often a small (or a pair of small) cartilage plates between them. These are supposed to be the homologues of the epipubis of the higher forms. There is no acetabular joint.

In the ganoids and teleosts, ossification begins, but there are no epipubic elements. The pelvic fins may migrate so as to lie in front of the pectoral.

The elasmobranchs have a true girdle, although there are no separate elements in it, and it does not ossify, there being but a continuous ischiopubic bar running from one acetabulum to the other, with an elongated iliac process running dorsad.

The pelvic girdle lies free of the vertebral column in all fishes, but in animals that have to support the body-weight upon their limbs, the pelvic girdle becomes definitely attached to the sacrum by the development of one or more sacral ribs.

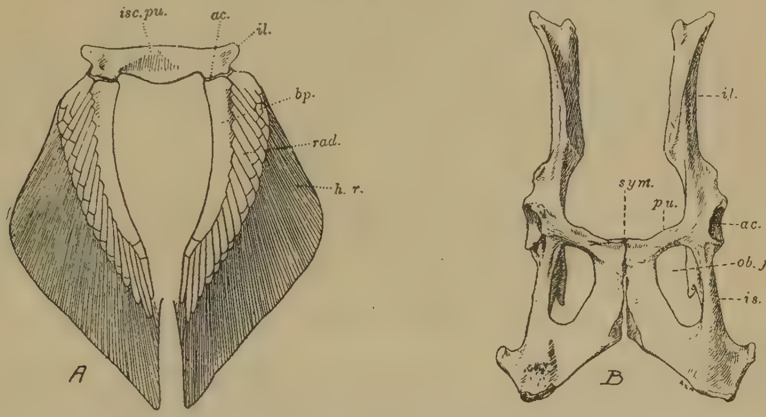


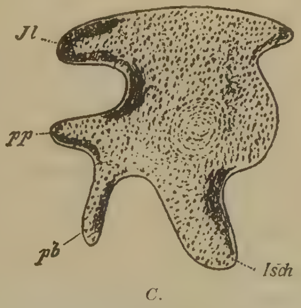
Fig. 419.

A—The skeleton of the pelvic fins and girdle of a female dogfish.

ac., Acetabular surface; *bp.*, basipterygium; *h.r.*, horny rays; *il.*, iliac process; *isc.pu.*, ischio-pubic region; *rad.*, cartilaginous rays.

B.—The pelvic girdle of a rabbit, from beneath.

ac., Acetabulum; *il.*, ilium; *is.*, ischium; *ob.f.*, obturator foramen; *pu.*, pubis; *sym.*, symphisis pubis. (From Borradaile).



C.—Anlage of pelvic girdle of 6-day chick embryo to show development.

Il, ileum; *Isch.*, ischium; *pb.*, pubis; *pp.*, pectineal process. (After Johnsohn).

In the mud puppy (Necturus, Fig. 375), the median cartilage extends forward as an epipubic process, while from the antero-lateral portion of each pubic bone or cartilage, a **pectineal process** extends, and, in the salamanders, to the extent of two or three somites, there is a cartilage formed independently of the pubis, in the linea alba, called the **ypsiloid cartilage.**

In the frog and other anura, the three pelvic bones are present, all of which participate in the forming of the acetabulum, although the ilium is very long and the ischio-pubis strongly compressed, so that the obturator foramen and ischio-pubic fenestra are absent.

In reptiles, the pelvic bones are more solid and distinct than in any of the lower forms. The ilium is often expanded, the ischio-pubic fenestra large, and the ischium and pubis united from side to side by an epipubic cartilage or a modification of this, known as the **ligamentum medium pelvis.**

In some turtles, the epipubic cartilage bounds the fenestra on the median side, but in all turtles, the fenestra and the obturator foramen are merged into one. In lizards, there may be a separate bone ossified from the posterior part of the epipubis. This bone is called the **os cloacae** or **hypo-ischium.**

In legless lizards, the pelvis is greatly reduced, while all trace of it is lost in the snakes, except the boas, and some **opoterodonts** (worm-like serpents). In the crocodiles, due to the oblique position of the pubes, the obturator foramen is very large. The pubes themselves do not unite with each other. There are cartilaginous tips on the medial end which may be separate epipubes. The lower end of the ilium also separates as a distinct bone.

It is interesting to note that the pelvis of **Dinosaurs** has the ilium arranged quite similar to that in birds. The sacrum also is somewhat similar, due, apparently, to the upright position in which these animals walked. The ischia are elongated, extending backward, and often uniting below, while the pubic bones extend forward and downward, and have strong post-pubic processes running parallel to the ischium, while often the ilium gives off an iliac spine near the acetabulum.

The **Pteryodactyls** also had elongated ilia, similar to the **Dinosaurs.** The ischium was then fused with the ilium, so that the pubis took no part in the forming of the acetabulum. In these the pelvic opening was very small.

In birds of the present time, the pelvic bones are fused; the ilium is quite long, and usually fused with the **synsacrum,** while the ischium and pubis extend backward.

The pubes lie in the position of the postpubes of **Dinosaurs,** and never meet below, except in ostriches. However, in the embryo, the pubes run forward, only gaining their final position later on. There is a pectineal process which arises in the acetabular region and extends forward, quite like the pubis in **Dinosaurs.** In the mammals, the obturator foramen and ischio-pubic fenestra are united; all three pelvic bones unite to form the acetabulum, although the ilium and ischium may extend in such a manner as to exclude the pubis from taking part in the formation of the fossa. Often an **acetabular** or **cotyloid bone** is formed between the ilium and pubic bones and this may fuse with any of the bones with which it comes in contact.

The inter-pubic cartilage in marsupials and monotremes may or may not persist throughout adult life. When it disappears and the bones unite solidly, but do not definitely ankylose, such union is called a **symphysis.**

In these non-placental mammals (the marsupials and monotremes just mentioned) there are also marsupial bones which first form in cartilage, and then extend forward from each pubis in the ventral abdominal wall. Their homology is unknown.

THE FREE APPENDAGES

In those animals, such as fishes living entirely in the water, the appendages are called **ichthyopterygia.** These are always paired fins. When definite legs or arms are formed, such as in all classes of the **tetrapoda,** such limbs and their modifications are known as **chiropterygia.** It is commonly supposed that the latter have developed from the former, but no one has yet been able to explain a method by which it came about. All explanations, however, assume that certain parts of primitive fins were retained and others likely modified, or, that certain parts were lost, which were originally present, the remaining parts then becoming modified. The lower ganoids have a primitive form of fin but with increasing complexity, there is a reduction of the basalia, either by entire disappearance or by fusion. The remaining ones are then modified, so that in elasmobranchs of the present time, we find the basalia usually number three in the pectoral and two in the pelvic fins, being named from before, backwards, as the pro, meso-, and meta-pterygium (Fig. 416)). The middle one is absent in the hind limbs. The radiales are jointed transversely, so as to give more flexibility. If these are arranged entirely on one side of the basalia, they are called **uniserial,** but if they occur also on the post-axial side, they are called **biserial.** The male elasmobranch has the pelvic fin divided into two lobes, the medial being called the **clasper,** or **mixipterygium.**

The anterior portion of the pectoral fin may develop as a strong defensive spine, sometimes connected with the poison gland. In eels the pelvic fin is lacking.

THE LIMBS

The legs **(chiropterygia)** of all tetrapoda are essentially alike (Fig. 420). Each consists of several regions, comparable in detail with each other. The proximal is the upper arm **(brachium)** or thigh **(femur)** con-

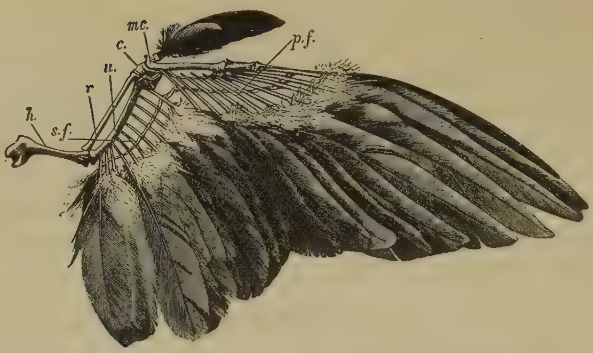
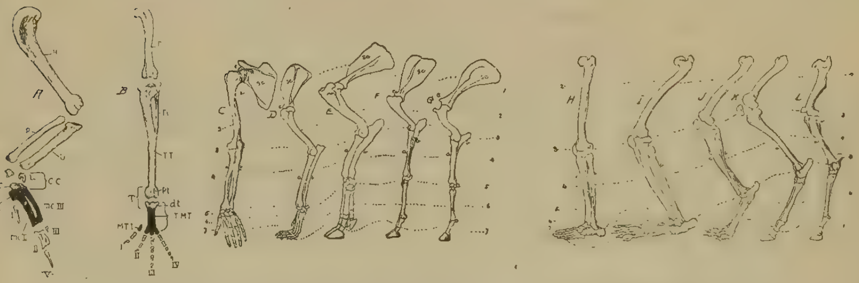


Fig. 420.—Comparisons of fore-limbs and hind-limbs.

1. Wing of a dove; *c*, carpals; *h*, humerus; *mc*, carpo-metacarpus; *p.f.*, primary feathers; *r.*, radius; *s.f.*, secondary feathers; *u.*, ulna.



A, and B.—The fore-limb and hind-limb of a bird compared. *H.*, Humerus; *R.*, radius; *U.*, ulna; *r.*, radiale; *u.*, ulnare; *C.*, distal carpals united to carpo-metacarpus; *CC.*, the whole carpal region; *MC.I.*, metacarpal of the thumb; *I.*, phalanx of the thumb; *MC.II.;* second metacarpus; *II.*, second digit; *MC.III.*, third metacarpus; *III.*, third digit. *F.*, femur; *T.T.*, tibio-tarsus; *Fi.*, fibula; *Pt.*, proximal tarsals united to lower end of tibia; *dt.*, distal tarsals united to upper end of metatarsus, forming a tarso-metatarsus (*T.MT.*); *T.*, entire tarsal region; *MT.I.*, first metatarsal, free; *I.-IV.*, toes.

C, D, E, F, G,—Anterior limb of man, dog, hog, sheep, and horse; *Sc*, Shoulder-blade; *c*, coracoid; *a*, *b*, bones of forearm; 5, bones of the wrist; 6, bones of the hand; 7, bones of the fingers.

H, I, J, K, L,—Posterior limb of man, monkey, dog, sheep, and horse: 1, Hip-joint; 2, thigh bone; 3, knee-joint; 4, bones of leg; 5, ankle-joint; 6, bones of foot; 7, bones of toes. (I, A, B, After Thomson, C to L, after Le Conte).

taining a single bone, the **humerus** or **femur** in the fore or hind limb respectively. The next region, the forearm **(antebrachium)** or **shank (crus)** contains two bones, a **radius** or **tibia** on the pre-axial, and an **ulna** or **fibula** on the postaxial side. Next follows the **podium** or hand **(manus)** in front and the foot **(pes)** behind, each consisting of three portions. The **basal podial region**, the wrist **(carpus)**, or ankle **(tarsus)**, consists of several small bones; the second division **(metapodium)** is the palm **(metacarpus)**, or instep **(metatarsus)**, and lastly come the fingers or toes **(digits)**, each digit consisting of several bones, the **phalanges.** These separate parts are included in the accompanying table, in which the terms given to the separate elements of the wrist and ankle of man are included.

FORE LIMB (Arm)			HIND LIMB (Leg)	
Upper arm (Brachium)		Humerus = Femur		Thigh
Fore arm (Antebrachium)		Radius = Tibia		Shank (Crus)
		Ulna = Fibula		
Basi-podium Wrist (Carpus)	**Naviculare (Scaphoid)**	Radiale = Tibiale	Astragalus (Talus)	Basi-podium Ankle (Tarsus)
	Lunatum	Intermedium = Intermedium		
	Triquetrum	Ulnare = Tibiale	Calcaneus	
		Centrale^{1+2} = Centrale^{1+2}	Naviculare pedis (Scaphoid)	
	Pisiforme			
	Multangulum majus Trapezium	Carpale^1 = Tarsale^1	Cuneiform^1	
	Multangulum minus (Trapezoides)	Carpale^2 = Tarsale^2	Cuneiform^2	
	Capitatum	Carpale^3 = Tarsale^3	Cuneiform^3	
	Hamatum	Carpale^4 = Tarsale^4	Cuboides	
		Carpale^5 = Tarsale^5		
Palm (Metapodium)		Metacarpale$^{1\text{-}5}$ = Metatarsale$^{1\text{-}5}$	(Metapodium)	Instep
Fingers	(Phalanges)	Digits$^{1\text{-}5}$ = Digits$^{1\text{-}5}$	(Phalanges)	Toes

The basal podial region, which is nearly typical in some reptiles, urodeles (Fig. 421), and man, consists of three rows of bones: a proximal of three bones, a radiale or tibiale on the anterior side, an ulnare or fibulare on the other, and an intermedium (not shown in the figure) between them. The distal row now consists of five carpales or tarsales numbered from the anterior side.

The third row is composed of one or two centrales between the other rows. The **metapodials** (Metacarpals and Metatarsals) and the digits, also numbered from one to five, have in some cases special names. The thumb (digit 1) is the **pollex,** the corresponding great toe being the **hallux,** while the fifth digit is called **minimus,** the second finger in the hand the **index,** and the fourth the **annulus.**

From this typical condition all forms of chiropterygia—legs, arms, wings—are derived by modification, fusion, or disappearance of parts.

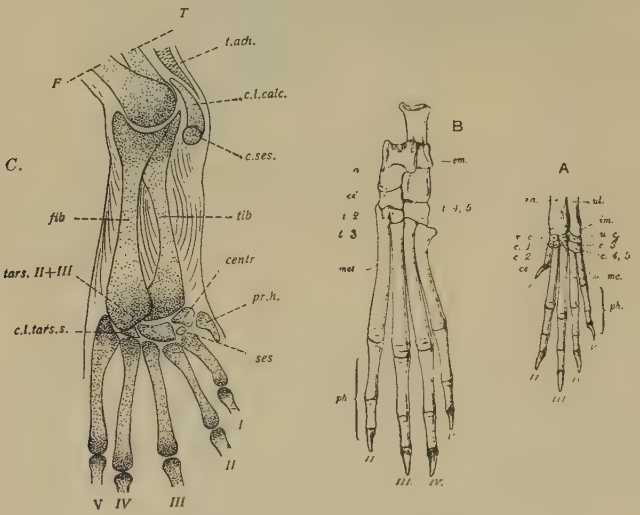


Fig. 421.—The skeleton of the left fore- and hind-feet of a rabbit. *A,* fore-foot; *B,* hind-foot.

a., Astragalus; *c.*1, first distal carpal or trapezium; *c.*2, second distal carpal or trapezoid; *c.*3, third distal carpal or os magnum; *c.*4,5, fused fourth and fifth distal carpals or unciform; *ce.*, centrale; *ce'.*, centrale of hind-foot or navicular; *cm.*, fibulare or calcaneus; *im.*, intermedium or semilunar; *mc.*, metacarpals; *met.*, metatarsals; *ph.*, phalanges; *ra.*, lower end of radius with its epiphysis; *r.c.*, radiale or scaphoid; *t.*2, second distal tarsal or mesocuneiform; *t.*3, third distal tarsal or ectocuneiform; *t.*4, 5, fused fourth and fifth distal tarsals or cuboid; *u.c.*, ulnare or cuneiform; *ul.*, lower end of ulnar with its epiphysis; *I.-V.*, digits. (From Borradaile).

C. Hindlimb of the frog tadpole shortly before metamorphosis. *centr,* centralis; *cl.calc.*, cartilaginous calcaneus ligament; *c.l.tars.s.*, supplementary cartilaginous tarsal ligament; *c.ses.*, sesamoid cartilage; *F,* fibula; *fib,* fibulare; *pr.h.*, prehallux; *ses,* sesamoid bone; *T,* tibia; *t.ach.*, tendon of Achilles; *tars, II* and *III,* second and third tarsals; *tib,* tibiale; *I-V,* phalanges. (After Tschernoff).

The more distal a part is, the more variable it is; reduction takes place on the margins of the appendage, the axial portions being the last to disappear. Occasionally, in various groups (amphibia, mammals) there occur what are interpreted as rudimentary additional digits—prehallux, prepollex, and postminimus—but their status is uncertain. There are also certain membrane-bones developed in the appendages, such as the **patella** (knee-cap) in some reptiles, birds, and many mammals, in the tendon that passes over the knee joint, the **fabellae** in the angle of the knee of a few mammals, and the **pisiforme** in the carpus of man and some other mammals.

We have already seen that in the frog the radius and ulna as well as tibia and fibula are fused together, while the tarsals are considerably elongated. Such fusion is not uncommon in many of the animals. The extent of fusion varies, however, considerably. In the reptile limb there is an intratarsal joint, so that the motion of the foot upon the leg lies between the two rows of tarsal bones, instead of between the tarsals and the bones of the shank. This is quite similar to the condition in birds.

Although limbs are lacking in the snakes and in some of the lizards, there is nevertheless a considerable increase in the number of phalanges in those reptiles where limbs do occur, while the more proximal bones shorten. In some of the ichthyosaurs there may be as many as a hundred phalanges in a single digit.

The skeleton of pterydactyls shows the fifth digit greatly developed, which forms a definite support for the wings, while the other digits remain more or less normal. In birds the wings are considerably modified (Fig. 420), although the structure is practically normal, up to the region of the carpus, the carpal bones being greatly reduced by fusion, while the metacarpals and digits, no matter what their modification, are only three in number.

Embryological studies of the chick show us that, although the first digit begins to develop, it is entirely lost, and the fifth metacarpal, which is present in the embryo, fuses early with the fourth, so that the digital formula is II, III, IV. Added to this, there is an extensive fusion of the bones of the tarsus and foot; the ankle joint is intratarsal, the basal row of tarsal bones fuses with the tibia, while the fibula is considerably reduced to form the tibio-tarsus. The tarsales unite in the same way with the fused metatarsals to form the tarso-metatarsus.

There are hardly ever more than four toes, but the number of phalanges increases from two in digit II, to five in digit V. Ostriches only have two toes, and many other birds three. In the mammals, especially in the higher forms, there is considerable motion of both hand and foot, rotation in the hand being especially noticeable by the motion of the lower end of the radius around the ulna. In the whales, the basal part of the forelimb is greatly shortened, while there is considerable multiplication of the phalanges. The hind limb is entirely lacking in some whales, while in others, there are two vestigeal bones supposed to be the femur and tibia, imbedded in the muscles of the trunk.

A supra- or **entepicondylar foramen** frequently perforates the inner lower end of the mammalian humerus, while in many forms the ulna is fused with the radius in varying degrees. However, the ulna, whether fused or not, always has on its proximal end a strong **olecranon** process which extends beyond the elbow joint for the attachment of the extensor muscles of the forearm.

The earliest prominences for the attachments of the muscles on the femur are known as **trochanters.** They vary from one to three. The

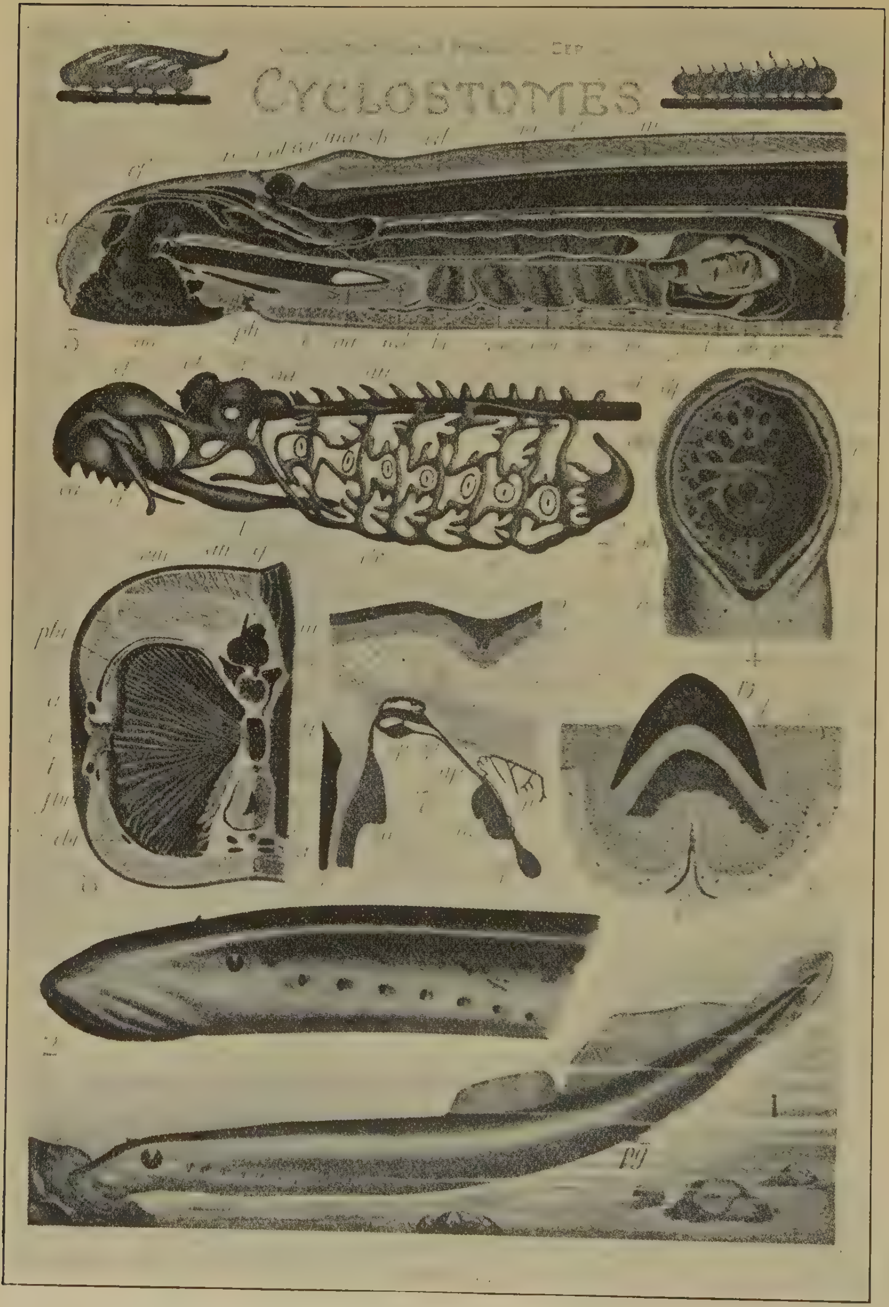


Fig. 422.

Cyclostomes, as exemplified by the marine lamprey, (*Petromyzon marinus*), from 60 cm. to 1 m. long, of European, West African, and North American waters, which goes up stream of the river in spring to lay eggs in the calm waters, and patella, or knee-cap bone, is analogous to the **olecranon process,** though it never joins the other bones.

The ankle joint in mammals is never intratarsal, but always between tarsal and crural bones.

Where the bones of the foot rest on the ground as in man and in the bear, such a foot is known as **plantigrade.** Where the toe of the foot includes only the distal phalanges such as in the dog and the cat,

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comes down again toward the sea in autumn; and the Planarian Lamprey, (*Petromyzon planari*), from 29 to 39 cm. long which inhabits the calm waters entirely, and is commonly found in rivers.

Fig. 1. A lamprey (*Petromyzon planari*) with its mouth fixed to a rock. *Pg.*, Genital papillae.

Fig. 2. Anterior part of the body of *Petromyzon marinus*, showing the seven branchial openings and the buccal cupping glass surrounded by little papillae. The olfactory opening lies in front of the eye.

Fig. 3. Section through the anterior region of *Petromyzon marinus.* The section, slightly oblique is nearly sagittal toward the front; it deviates dorsad and downward in order to take in the last of the left branchial sacs; *cb.*, buccal cupping glass; *ca.*, ringed cartilage carrying the principal teeth; *cf.*, cartilaginous pieces of the face; *l*, lingual sucker, (the posterior part of the sucker has not been taken into the section) is shown surrounded by its sheath; *ml.*, muscles of the lingual sucker; *ph.*, pharynx; *oe.*, oesophagus; *m.oe.*, sphincter closing the entrance of the oesophagus; *a.br.*, branchial aqueduct, showing the seven openings to the branchial sacs; *va.*, valvular apparatus closing the entrance to the aqueduct; br_1-br_7, branchial pockets continuing into the coelomic peribranchial cavities, the one being separated from the other by septa; *C*, heart; the auricle has been raised partly to show the openings by which it communicates with (1) the ventricle (2) with the sinus venosus, *sv.*, as one sees them both from behind; *vc.*, entrance of the cardinal veins into the sinus; *j.*, jugular vein; *vh.*, hepatic vein; *tao.*, aortic trunk, with the conus arteriosus and its valvular apparatus at the base of the trunk; *ao.*, aortic roots reuniting on a level with the fifth branchial opening to form the aorta; *n.*, nostril; *sh.*, bottom of the hypophysial sac with a valvular sac lying before it; *cer.*, brain; *m.*, medulla; *cd.*, dorsal cord; *f*, liver; *ov.*, ovary; *p.*, posterior cul-de-sac of the branchial enclosure which protects the pericardium.

Fig. 4. Mouth of the Marine Lamprey. *de.*, teeth of the head of the lingual sucker; *di.*, lower median tooth; *ap.*, principal lateral teeth grouped in twos; *da.*, accessory teeth; *ph*, sensory papillae of the buccal lip; *os.*, cutaneous sensory organs.

Fig. 5. Anterior region of the skeleton: *ca.*, ringed cartilage carrying the principal teeth, *d.*, *cf.*, cartilaginous parts of the face; *cr.*, brain box; *l*, lingual cartilage; *ol*, olfactory capsule; *cd.*, dorsal cord; *an.*, the two neural arches, anterior and posterior, of the same metamere; *cbr.*, branchial enclosure; *a*, cartilaginous rings surrounding the opening of the external gills; *p*, posterior cul-de-sac of the branchial enclosure; holding the heart (after Parker); the left half only of the skeleton is represented.

Fig. 6. Section of a horny tooth (odontoid) of lamprey: *ep.*, buccal epithelium; *pa.*, dermal papillae; *D*, tooth in use; *d*, replacing tooth, in process of development; *k*, horn producing cellules (After Warren).

Fig. 7. Sagittal section of the Pineal Eye.: *ep.*, epidermis; *de.*, dermis; *op.*, pineal eye; *np.*, pineal nerve; *pp.*, parapineal eye; *ha.*, commissure and habenular ganglion; *ch*, chorioid curtain and lamella concealing the mesencephalon; *ca.*, anterior commissure; on the walls of the thalamencephalon; *cp.*, posterior commissure, *cr.*, cranial cartilage (after Studnicka).

Fig. 8. Section of a branchial pocket, passing through internal and external openings. (By reason of the situation of these two openings, the section of the left side of the figure is practically on a plane which places the face to the observer and forms an angle of 45° with the median plane of the animal; the rest of the section, which is only drawn in, is entirely transverse, and therefore seems shortened). *cd*, dorsal cord; *an*, neural arch; *m*, section of the medulla; *g*, fatty tissue completing the padding of the neural canal; *oe*, oesophagus and beneath, the aorta; *abr*, branchial aqueduct; *t.ao.*, aortic trunk; *l*, lingual cartilage and its muscular sheath; *j*, jugular vein; *cae*, appendages of the general cavity; *cbr.*, section of the divers pieces of the branchial enclosure; *o*, internal branchial orifice at the interior of the pocket; *o′*, external branchial opening, with its threefold valves and cartilaginous ring, *a.br.*, wall of the branchial pocket; *fbd*, branchial leaves; *par.*, peribranchial cavity slightly taken in section; *mu*, muscles.

(1) Vignettes of the title: Scheme of the respiratory apparatus of two cyclostomes seen from the ventral surface: the oesophagus and the respiratory sacs of the left side (G) only are represented; the horizontal flesh is turned toward the caudal end of the animal; the oesophageo-cutaneous canal, which exists only on the left side is figured in discontinued tracts. To the left the respiratory apparatus of *Myxine* is seen (six branchial pockets with efferent canals running to a single opening) to the right, the respiratory apparatus of *Bdellostoma polytrema* (10-14 branchial pockets). (After Dean in Goodrich). (From the chart of Remy Perrier & Cépède).

it is called a **digitigrade foot**, while, if the animal, such as the horse or cow, walks upon hoofs which are homologous to the nails on the hands and feet of higher forms, such a foot is called an **unguligrade foot.**

There may be variations and fusions in all these animals. For example, in the horse, it is only the third digit which persists in a functional condition.

SUMMARY OF THE CRANIUM

CYCLOSTOMATA

The cranium lies entirely beneath the brain, and forms neither side nor roof for the latter (Fig. 422). The cranial cartilages are sometimes said to be homologous with those of the embryonic fish skull.

DOGFISH

The investing bones are closely applied to the roof and floor of the chondrocranium, and modify its form considerably by projecting beyond the cartilaginous part, and concealing apertures and cavities (Fig. 407). The large **frontals** cover the greater part of the roof of the skull, concealing the fontanelles and furnishing roofs to the orbits. Immediately behind the frontals is a pair of very small **parietals**; in front of them is an unpaired **supra-ethmoid,** to the sides of which are attached a pair of small **nasals.** On the ventral surface is the large **parasphenoid,** which forms a kind of clamp to the whole cartilaginous skull-floor; and in front of, and below, the parasphenoid is the **toothed vomer.** Encircling the orbit is a ring of scale-like bones, the **sub-orbitals.**

PISCES

The fish skull (Fig. 409) is covered above and below by numerous dermal investment bones which are much like those of the primitive extinct amphibia **Stegocephali.** By boiling, all the investment bones are loosened and when removed a chondrocranium like that of the dogfish is seen.

In fishes there are primary and secondary structures in the jaw as in the cranium. The primary upper jaw **(palatoquadrate)** is considered homologous with the upper jaw of the dogfish. It does not, however, remain cartilaginous but is ossified by five replacing bones: the **toothed palatine** in front which articulates with the **olfactory capsule**; the **pterygoid** on the ventral edge; the **mesopterygoids** on the dorsal edge of the original cartilaginous bar, and the **quadrate** at the posterior end of the latter. These bones do not enter into the gap, and consequently do not constitute the actual upper jaw of the adult fish. External to them are two large investing bones, the **premaxilla** and the **maxilla,** which together, form the actual or **secondary upper jaw.** They both bear teeth.

A small scale-like bone, the **jugal,** is attached to the posterior end of the maxilla.

The lower jaw is quite similarly modified. The **articulare** articulates with the quadrate and is continued forward by a narrow pointed rod of cartilage which is really the unossified distal end of the primary **Meckel's cartilage** (the primary lower jaw). The articulare is the ossified proximal end, therefore, a replacing bone. Then there is a large toothed investing bone which ensheaths Meckel's cartilage and forms the main part of the secondary lower jaw. This is the **dentary.** There is also a small investing bone, the **angular,** which is attached to the lower and hinder end of the **articulare.**

The upper jaw connects with the cranium partly by the articulation of the **palatine** with the olfactory region and partly by means of a **suspensorium** formed of two bones separated by a cartilaginous interval. The larger, usually called the **hyomandibular,** articulates with the **auditory capsule** by a facet and the small, pointed **symplectic** fits into a groove in the quadrate. Both bones are attached by fibrous tissue to the quadrate and metapterygoid, and in this way the suspensorium and palatoquadrate together form an inverted arch which articulates freely in front with the olfactory, and behind with the auditory capsule. This gives rise to an extremely mobile upper jaw.

The chondrocranium is a solid one-piece capsule which completely encloses the brain and the principal sense organs. The cranium proper is fused with paired nasal capsules and paired auditory capsules.

Closely associated with the skull, but not fused with it, is the mandibular skeleton, consisting of an upper jaw **(pterygoquadrate cartilages)** and a lower jaw **(Meckel's Cartilage).** Back of the jaw are the visceral arches. These are composed of upper and lower parts like the jaws. The first pair is specialized as the **hyoid arch,** the five others being the more generalized branchial arches that afford support for the gills.

AMPHIBIA

The skull (Fig. 410) articulates with the **atlas** by **two condyles** which are formed by the **exoccipitals.** There is an **auditory columellar apparatus** fitting into the **fenestra ovalis.**

AVES

The skull (Fig. 412) is rounded, has large orbits, and the facial bones are extended out upon the beak. The quadrate is movable and articulates with the squamosal. There is a **single occipital condyle.** There are no teeth in modern forms. The cervical vertebrae have paddle-shaped articular surfaces which give the neck great flexibility, and thus make the beak a very versatile instrument.

REPTILIA

The special features in the turtle skull (Figs. 411, 413) are these: teeth are absent, the maxillary, premaxillary, and dentary bones are covered with hard, chitinous sheaths which form the upper and lower members of the cutting beak; the vomer is a single unpaired median bone, and there are no lachrymals or ectopterygoids. The pterygoids send wings of bone inward. The wings and the palatines form a continuous roof of the mouth; the supraoccipital is prolonged backward into a large, narrow process upon which are inserted the heavy neck muscles. All of these bones, even the quadrate, are firmly united into a solid cranium. There is **only one occipital condyle.**

MAMMALIA

The skull of the mammal (Figs. 413, 414) is more compact than that of lower forms; consequently, it contains fewer elements than the skull of reptiles. The following reptilian bones are not found in the adult mammalian cranium: pre- and post- orbitals, pre- and post- frontals, basi-pterygoids, quadrato-jugals, and supra temporals. The lower jaw is reduced to a single pair of bones in the mammal, the angulare, splenial, and articulare being absent. The latter is often said to have been drawn in to form the **malleus** of the ear bonelets and the **quadrate** has been drawn in to form the **incus** bonelet, while a remnant of the hyomandibular cartilage forms the **stapes.** The whalebone whale (baleen whale, Fig. 392), shows the highest type of the so-called **adaptive specialization** among mammals. Here the teeth are rudimentary and functionless though present in the young. In the adult they are replaced by baleen. The nostrils are paired, the skull symmetrical, the sternum is single, while the ribs are one-headed and articulate only with the transverse processes of the vertebrae.

SUMMARY OF THE SKELETAL SYSTEM

THE DOGFISH

The vertebrae develop at the intersection of the myosepta with the mesenchyme that surrounds the notochord and neural tube. Each individual vertebra is formed by the union of the two caudal halves of the two sclerotomes of one segment with the cephalic halves of the two sclerotomes of the next succeeding segment (Fig. 305). The vertebrae therefore alternate with the myotomes.

As the vertebrae and ribs are first formed in cartilage produced by the activity of mesenchyme, so also, bones which form later are true cartilage bones. In the elasmobranchs, the entire skeleton is made up of cartilage with only a slight impregnation of calcareous matter.

Each vertebra begins as four pair of cartilages (called **arcualia)** which surround the notochord. Dorsally these are an anterior pair of basidorsals and a posterior pair of interdorsals. Ventrally there is an anterior pair of basiventrals and a posterior pair of interventrals.

In some fish and in extinct **Amphibia** and reptiles these cartilages remain more or less separate. In most vertebrates, however, parts are lost, while the remaining portions fuse together to form a single vertebra which is then composed of a centrum (which encloses the notochord); a dorsally directed neural arch (which encloses the spinal cord); and a haemal arch (enclosing the blood vessels). (Figs. 352, 404.)

The neural arch is made up of the fused basidorsals, and the haemal arch of the fused basiventrals, while the centrum develops from varying parts in different groups of animals.

In the elasmobranchs the centrum is formed within the notochordal sheath, thus forming a **chordal centrum** as contradistinguished from that of nearly all other vertebrates where the centra are produced by the fusion of certain arcualia to form a **perichordal** or **arch centrum.**

There are two kinds of ribs, namely: those which arise at the intersection of the myosepta with the horizontal skeletogenous septum (true or intermuscular ribs), (Fig. 423, q), and those which arise at the intersection of the myosepta with the ventral skeletogenous septum or its derivatives (false or subperitoneal ribs), (Fig. 423, r). Teleosts develop the latter type, while all other vertebrates develop true ribs.

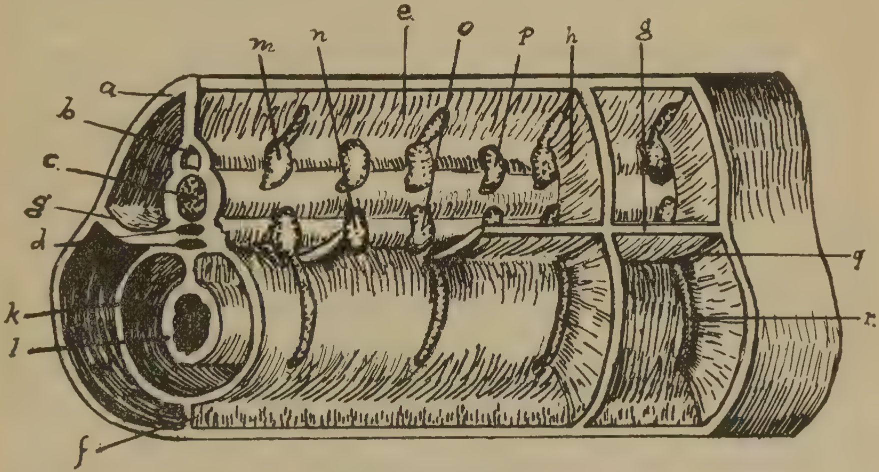


Fig. 423.—Diagram to show the skeleton-forming septa in the trunk region of a vertebrate.

a, skin; *b*, neural tube; *c*, notochord; *d*, blood vessel; *e*, dorsal skeletogenous septum; *f*, ventral skeletogenous septum; *g*, horizontal skeletogenous septum; *h*, myoseptum; *i*, epaxial part of the myotome; *j*, hypaxial part of the myotome; *k*, coelom; *l*, intestine; *m-p*, cartilages from which the vertebrae are formed; *m*, basidorsal; *n*, interventral; *o*, basiventral; *p*, interdorsal; *q*, intermuscular rib; *r*, subperitoneal rib. Note the positions of the vertebral cartilages and ribs with respect to the skeletogenous septa. (From Hyman after Goodrich).

Some fishes (such as trout, salmon, herring, and polypterus), however, develop both types of ribs and even additional ones at various levels of the myosepta.

The vertebrae are connected with each other by a strand of notochordal tissue that perforates all the vertebrae like the string through a chain of beads.

The fins have ray-like supports of cartilage and the pectoral and pelvic limb-skeletons are supported upon simple horseshoe-shaped pectoral and pelvic girdles, each composed of a single piece of cartilage.

AMPHIBIA

A short cervical and sacral region appear in **Amphibia,** the cervical becoming longer in the higher forms of vertebrates. The pelvic girdle lies free in fishes, but in all other vertebrae it is immovably attached to the sacrum. Three fingers develop early in the amphibian foot, although a fourth appears quite late in development (Fig. 421). This fourth finger lies well down on the ulnar side of the hand. Then a rudiment of the fifth (the little finger) appears as a mere bump. The thumb, index, and second finger, therefore, seem to be phylogenetically the oldest digits. This is important in connection with the loss of fingers in other vertebrates, as the last to develop is usually the first to be lost. In the amphibian we find feet instead of fins. This brings a change in the type of movements in the animal, for with fins, an animal can only paddle backwards and forwards. The muscles are, therefore, decidedly different and nearly all trace of the segmental arrangement in them is lost. Animals which live on land are relatively heavier than those which live in water, so there is need of a much more rigid axial skeleton as well as stronger limb girdles, and limb skeleton. This condition is brought about by a more complete ossification of the parts of the skeleton that bear the most weight. Exoskeleton parts also tend to disappear so that in modern amphibia, the exoskeleton is entirely absent with the exception of the **Caecilians,** where it is rudimentary. In the **Stegocephalians** there is a head armor while the exoskeleton is lacking on the rest of the body. The sternum first appears in amphibia.

REPTILIA

In reptiles, birds and mammals the cervical region is longer than that of the **Amphibia** and the trunk region is divided into an anterior thoracic region with long ribs and a more caudal lumbar region with short ribs or with none.

In all vertebrates rudimentary ribs are usually found on the cervical and sacral vertebrae when these regions are present.

Fossil remains show that there were many more plates and scutes on the turtles of the past than on those of the present. Both longitudinal and transverse rows of elements have disappeared, the whole system now being greatly simplified. Most species of turtles to-day show a certain percentage of individuals with supernumerary scutes and plates. (Fig. 424.)

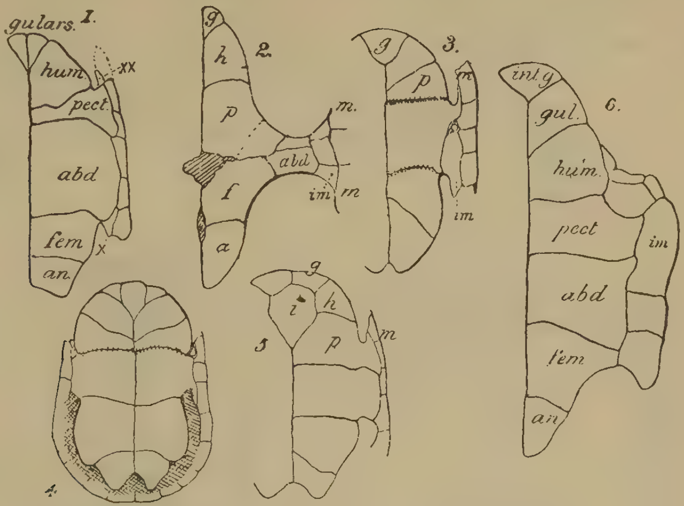


Fig. 424. Various plastra and their horny shields.

1, *Testudo ibera;* 2, *Macroclemmys temmincki;* 3, *Cinosternum odoratum;* 4, *Sternothaerus nigricans;* 5, *Chelodina longicollis;* 6, *Chelone mydas.* *a* or *an,* anal shield; *abd,* abdominal shield; *f* or *fem,* femoral; *g* or *gul,* gular, unpaired in 3; *h* or *hum,* humeral shield; *i* or *int.g,* intergular; *im,* inframarginals; *m,* marginals; *p* or *pect,* pectoral; *x* (in 1) inguinal shield constituting with the axillary *xx,* the last trace of inframarginals. (After Gadow).

In the trunk region the vertebrae are rigidly united to the narrow, paddle-like ribs (Fig. 425). There are eight cervical, ten thoracic, two sacral, and a variable number of caudal vertebrae, which are procoelous in form (Fig. 404). A peculiar thing in the turtle is that both pectoral and pelvic girdles are **inside instead** of outside the ribs. They actually arise from primordia internal to the ribs so it is not a case of migration. No one has yet been able to give a satisfactory explanation of this.

The pectoral girdle (Figs. 416, 417) is made up of a triradiate group of flattened bones: the **scapula,** the **procoracoid,** and the **coracoid,** the last being the largest. These three bones unite to form a socket which receives the head of the humerus. The pelvic arch is more compact. It consists of **pubis, ischium,** and **ilium,** which unite to form the **acetabulum** for the head of the femur. Membrane bones are never found in the pelvic girdle of any animal.

AVES

The sternum is keeled (Figs. 416, 418), except in such birds as the ostrich, and the ribs have **uncinate processes** (Fig. 418, B, u.p.) except in **Screamers** (members of the family **Palamedeidae).** The trunk vertebrae

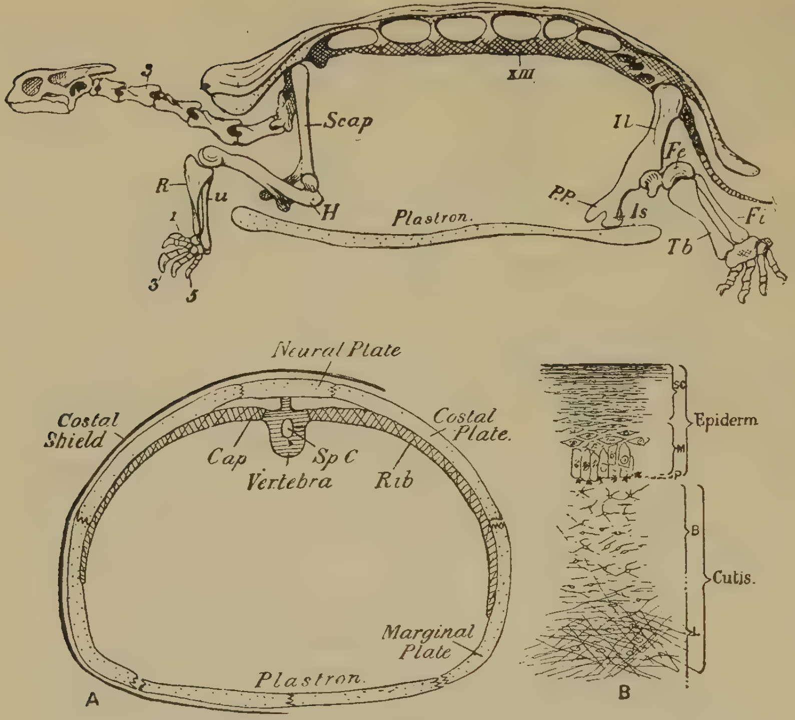


Fig. 425.

A. Diagrammatic transverse section through the shell of *Testudo*. The horny shields have been removed from the right side. On the left side one can see the neural, costal, marginal, and pectoral shields. The bony dermal plates are dotted. *Cap*, capitular portion of rib; *Sp.C*, position of spinal cord. *B*, Vertical section through part of the shell, magnified and diagrammatic. *B*, Bony layer of cutis; *L*, leathery layer of the cutis; *M*, cells of the Malpighian layer; *P*, star-shaped pigment-cells; *Sc*, stratum corneum composing the horny shields. *C*. Diagram of skeleton of *Testudo elephantopus*, after removal of the left half of the carapace. The plastron is indicated by a section through the middle line. *Fe*, femur, foreshortened; *Fi*, fibula; *H*, humerus; *Il*, ilium; *Is*, ischium; *P.P.*, pubis; *R*, radius; *Scap*, scapula; *Tb*, tibia; *u*, ulna; 3, third cervical vertebra; 1, 3, 5, first, third and fifth fingers; XIII, thirteenth (fifth thoracic) vertebra. (After Gadow).

are mostly fused. There are three or four pre-caudal vertebrae with terminal **pygostyle** (Fig. 418), two cervical, and three to nine thoracic ribs, the latter attached to the sternum. The pectoral girdle is made up of paired, blade-like **scapulae, paired coracoids** which unite with the **sternum,** and **three clavicles** fused in the middle to form the **"wishbone"** or furcula. The pelvic girdle is a solid bone, composed of the fused **ischia, ilia,** and **pubes.** The pelvis is firmly fused with the sacral vertebrae. The leg skeleton consists of a large **femur,** a slender **fibula,** and a long, stout **tibiotarsus,** made up of the fused tibia and proximal tarsal bones; the ankle joint is between the tibio-tarsus and the tarso-metatarsus.

The foot has four digits, the hallux usually being directed backward.

MAMMALIA

The coracoid portion of the pectoral girdle (Fig. 416) is reduced to a small coracoid process in all placentals, while the scapula of all mammals possesses **a spinous process.**

There are usually **paired clavicles** and a median **unpaired interclavicle** in all land mammals. These are membrane bones.

CHAPTER LI.

THE DIGESTIVE SYSTEM

It will be remembered that all multicellular animals pass through a blastula stage consisting of a hollow sphere composed of a single layer of cells, which then indents to form a gastrula.

This means that there are now two layers of cells where there was only one before. The outer layer is called the **ectoderm** and the inner the **endoderm.** The indented end closes up, leaving a hollow tube composed entirely of endoderm in the center, which, due to its being used for other purposes than the ectoderm, and lying **within** the body, undergoes totally different experiences than does the outer part of the body, and these different experiences modify its structure. This hollow tube is the **primitive digestive tract.** It will thus be seen that the digestive apparatus is the very first one of the various systems of an organism to differentiate.

This distinctive cavity is called the **gastrocoele.** In the lower invertebrates this gastrocoele remains as a blind cavity with but a single opening. It is among the worms that it first becomes converted into a complete canal by the formation of an anal opening. In animals up to this stage the same opening serves both for ingestion and egestion.

What is considered a distinct advance in the development of multicellular animals is the development of a **coelom,** or **body cavity,** lying between the digestive tract just mentioned, and the body wall. Up to the time this coelom has developed, the body of the animal consists of a single tube and its wall. But after the coelom has developed there is established a **secondary** open space **between** the **hollow digestive tube** and the **body wall.**

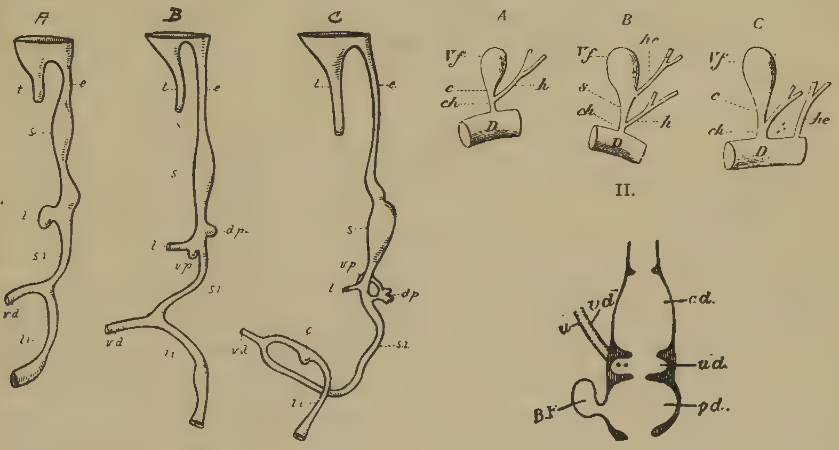
The coelom is developed by **protrusions** or **diverticula** pushing off from the original digestive tube (Fig. 426). This means that the digestive canal of the higher animals only represents a portion of the digestive system of lower animals.

Another departure from the lower organisms consists in the fact that the mouth and anal opening are not developed in the same way in the vertebrates as they are in the lower forms of animals.

In the lower forms, after gastrulation, the **indented end remains open,** thus serving as both mouth and anal opening at the same time. In the higher forms, however, this indented end **closes** so that there is a completely closed hollow tube composed of endoderm on the inside of the body. To form the mouth and anal opening a new indentation at both the cephalic and caudal ends takes place.

This indentation coming from the outer layer of the body means that mouth and anus are composed of **ectoderm** and not endoderm as is the central digestive tube. After the indentation has gone far enough, the thin plate of cells separating the central digestive tube from the mouth and anus breaks through, so that a continuous opening is formed, from the mouth through the digestive canal to the anal opening.

All the additional structures that go to make up the digestive system as well as the respiratory system are formed by inpushings or outpushings (Fig. 426) of this elementary digestive tract and it will be necessary to remember in one's study of all the higher forms, that no matter how many of these inpushings or outpushings there may develop, and no matter how lengthy the digestive tube may grow and coil, if it be straightened out it will to all intents and purposes be a continuous hollow tube whose interior is really **outside** the body in so far as it is subject to all the external conditions to which the body itself is subject. In other words, one may the better understand this if a hollow gas pipe, open at both ends, is thought of. The hollow, straight opening, through which the eye can see, represents the digestive canal. The metal of which the pipe is composed represents the walls of the digestive tube.



I. II. III.

Fig. 426.

I. Diagrams to show method of outpushings in digestive tract. A, 6mm. pig embryo; B, same at 8 mm.; C, same at 10 mm. *t*, trachea; *e*, oesophagus; *s*, stomach; *l*, liver; *d.p.*, dorsal pancreas; *v.p.*, ventral pancreas; *s.i.*, small intestine; *c*, caecum; *v.d.*, vitelline duct. (From Carey, Journal of General Physiology. Vol. III. No. 1).

II. Three schematic views of variations in the ducts leading from the gall-bladder. *c* and *s*, cystic duct; *ch*, ductus choledochus; *h*, hepatic duct; *hc*, hepato-cystic duct; *he*, hepato-enteric duct; *vf*, gall-bladder. (From Schimkewitsch after Wiedersheim).

III. A diagrammatic section of the cloaca of a male bird. (After Gadow.) *cd.*, Upper region of cloaca into which rectum opens; *ud.*, median region into which ureter (*u.*) and vas deferens (*vd.*) open from each side; *pd.*, posterior region into which the bursa Fabricii (*B.F.*) opens.

It can, therefore, easily be seen that any conditions such as dust and moisture that may be in the atmosphere surrounding the outside of this pipe will quite likely be found on the inside.

During the development of the nervous system there is a connection between the lumen of the neural tube and the gastrular mouth so that there is a **temporary connection between the neural tube and the gastrocoele.** This connection is called the **neurenteric canal** (Fig. 328, B, ne.c). This connection, however, soon disappears so that the **gastrocoele is a closed sac** with no opening whatever to the outside of the body **until the mouth and anal openings are pushed in** from the ectoderm as already mentioned.

Definite names are given to the various structures of the growing embryo. The mouth opening is called the **stomatodeum** ( ). The mid portion connecting the mouth with the anal opening is called the **mesodeum** ( ), and the caudal part, which like the stomatodeum is ectodermic, is known as the **proctodeum.**

This does not mean that in every animal in which an ectodermal mouth and anus has developed that the ectodermal structures take up the same length of the digestive system. In the **articulates** (crustaceans, insects, and spiders) the stomatodeum and proctodeum are much longer and larger proportionately to the mesodeum than in the higher forms of life, in fact, **in the vertebrates, the digestive canal is mainly mesodeal and therefore endodermic.** The mouth and anal regions composed of ectoderm are but a small portion of the entire digestive system.

The jaws, teeth, and tongue, which will be taken up separately, do not develop from the simple digestive tube which has just been described, but the other parts of the digestive system, even the most complicated ones, have come from this tube alone by a growing in length, by enlargements of various kinds, by foldings, by outpushings and inpushings. Not only have such complex organs as the liver and spleen, thyroid and thymus glands, as well as many others, come from this endodermal tube, but the entire breathing apparatus of chordates has arisen from its cephalic end.

As some chordates, such as fishes, live in water, they require a totally different type of breathing mechanism than those which live on land, yet their **branchial** or gill system and the land living **pulmonary** or **lung system** have in each case developed from the same simple digestive tube. It must be remembered that this is only true of chordates. Animals not chordates do not show such close relationship between the digestive and respiratory systems.

The intestinal tract, if cut in cross section and examined microscopically will be found to be composed of four layers of **different types** of cells. Starting from the inner layer we find them in the following order (Fig. 291):

mucosa
submucosa
muscularia { circular
longitudinal
serosa

It is in the mucosa or the inner layer that the glands which produce the digestive juices are found. Here, too, are a few scattered involuntary muscle fibers and lymphatic vessels for carrying away the nutriment after it has been changed into a condition so it can be assimilated.

The submucosa is a thin layer of connective tissue supporting the mucosa.

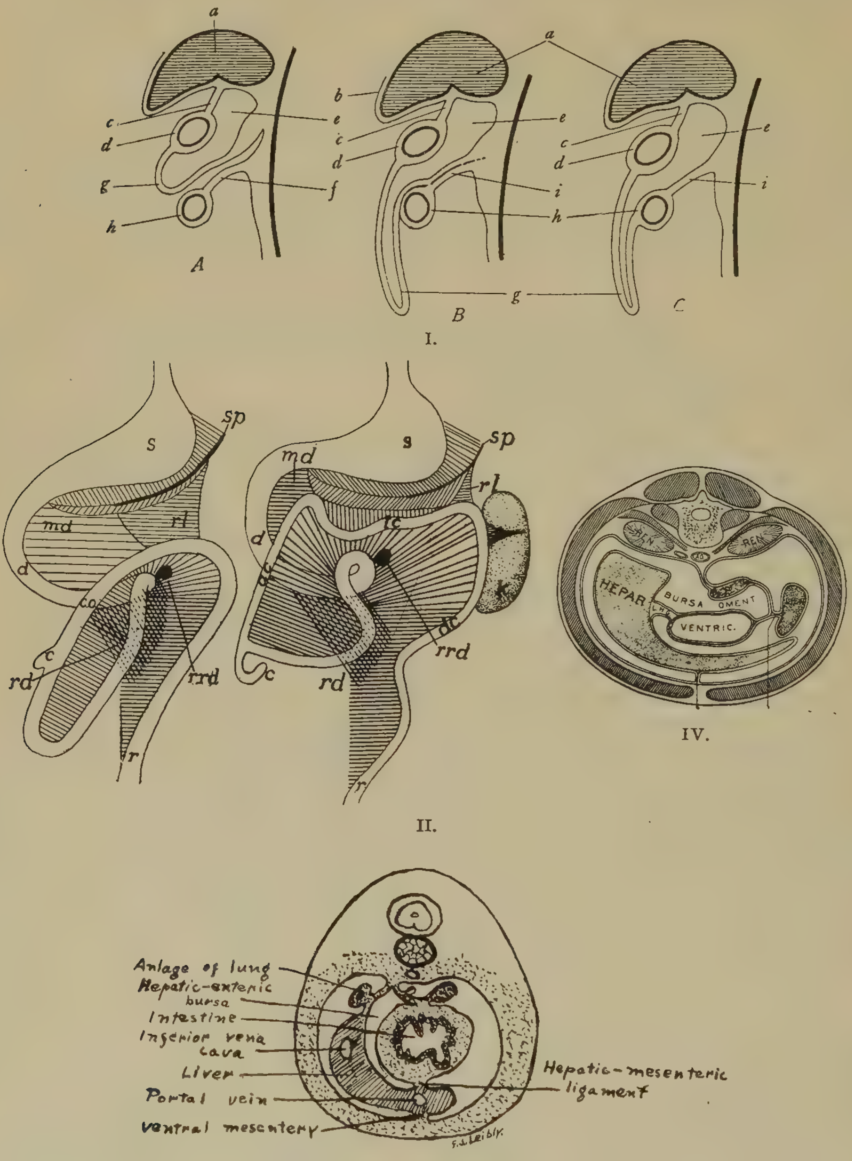
The musculosa varies a good deal, but essentially it is composed of two layers of **involuntary muscle cells** both circular and longitudinal, the former lying toward the lumen.

The circular muscles by contracting, lengthen the intestines while the contraction of the longitudinal muscles shorten and thicken it. These two actions cause the **peristaltic movement** occurring during digestion, pushing the food forward and also permitting the various folds and little finger-like projections, called **villi**, to come in contact with all of the material that has been ingested.

In the higher forms, especially in the human being, there are some thirty feet or more of small intestine as contrasted with three or four feet of large. The reason for this can be understood quite readily when it is appreciated that a **two-inch water pipe holds eight times as much as a pipe one inch in diameter.** The great mass of material that is ingested is of no value whatever to the animal ingesting it unless such food can be reduced to a more or less liquid state and be absorbed by the mucous lining of the intestinal tract. Digestion, though beginning in the stomach, really takes place in the small intestine. The smaller this intestine is in diameter, therefore, and the more folds the mucosa has, the more readily will the food, after it is sent through the digestive canal, be likely to come in contact with the mucosa and be absorbed.

It is important to understand this as it will throw much light upon various physiological functions of digestion, for, it will be seen that the little finger-like villi must actually do the work of absorbing. That is, after ingested material is ready for absorption, it does not pass by any rule of gravity or mechanics into any definite opening; but these little projections must actually reach out and drink in the necessary material. As these little villi must in turn be kept in good condition and capable of performing their functions by their nerve and blood supplies, it follows, that where the nerve and blood supply is either weakened or lost, the animal may die of starvation regardless of how much food it may ingest.

Many glands are found in the mucosa. Some of the larger ones have pushed their way further and further back so that they have not only passed through the submucosa and musculosa, but have gone far beyond. The liver and pancreas are good examples of those which have left the



I.

II.

IV.

III.

Fig. 427.

I. Diagrams to show formation of greater omentum in mammals and the fusion of the mesogaster and the mesocolon. A, early stage in which the mesogaster is beginning to form a bag at *g*. B, the mesogaster is drawn posteriorly into a main digestive tract almost entirely but are still connected with it by small ducts.

The glands push their way through both submucosa and musculosa **but,** as they push against the **serosa** this seems to stretch out ahead of all these outpushings, forming a covering for the outgrowths. This is why not only the liver and pancreas, but every organ in the abdominal cavity, is **completely covered by this serous layer,** which when thought of in its entirety is called the **peritoneum.**

The kidneys form a single exception to the statement that **all organs** in the abdominal cavity are completely covered with peritoneum. These do not spring from the digestive tract, however, and will be discussed later with the **uro-genital system.**

The entire digestive canal is covered with this serous layer. Figure 427 shows just how this develops and why it is that, while there is a **single layer** of **serosa over the ventral side** of the intestinal tract there are **two layers running dorsalward which are attached close to the ventral portion of the spinal region forming the sustaining ligaments.**

Probably this will be made clear if one place an ordinary sheet of paper on the desk before him and lay a pencil at right angles to the long axis of the sheet. By picking up the two ends of the paper so that the pencil is held within the fold it will be seen that **under** the pencil there is only **one layer of paper** but **above** it **there are two.** The various outpushings of the intestinal tract push the serosa before them just as the pencil does the paper in this case.

The two layers running dorsalward from the organ and forming the sustaining ligament are called the **mesentery,** and it is **between these two sheets of mesentery that the blood supply of the organ is carried.**

If it be remembered that the digestive tract begins as a single tube, approximately the same length as that of the body in which it grows, and if the various elongations, outpushings, and inpushings are then followed through the embryonic period, considerable light will be thrown upon our understanding of the adult structure (Fig. 428).

One must, however, be wary in comparing different type-forms of animals, as well as animals of the same species at different stages of their development, or there will be little validity in the comparisons.

The **first portions** of the digestive tract **to differentiate** are the

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long bag *g* which is the greater omentum; the mesogaster and mesocolon are fusing at *i*. C, completion of the fusion of mesogaster and mesocolon at *i*. *a*, liver; *b*, serosa of the liver; *c*, lesser omentum or gastro-hepato-duodenal ligament; *d*, stomach; *e*, lesser peritoneal sac or cavity of the greater omentum; *f*, mesocolon; *g*, portion of the mesogaster which forms the greater omentum; *h*, intestine; *i*, fusion of the mesogaster and mesocolon. (From Hyman after Hertwig).

II. Scheme of digestive canal and mesenteries in human embryos, 30 and 50 mm. long. *ac*, ascending colon; *c*, caecum; *co*, colon; *d*, duodenum; *dc*, descending colon; *k*, kidney; *r*, rectum; *rd*, recto-duodenal ligament; *rl*, recto-lienal ligament; *rrd*, recto-duodenal recess; *s*, stomach; *sp*, spleen; *tc*, transverse colon. (From Kingsley after Klaatsh).

III. Transverse section of a salamander embryo in the region of the liver. (Redrawn from Maurer).

IV. Schematic arrangement to show the development of the omental bursa. (After Corning). *P*, Pancreas; *Ao*, Aorta; *L.H.G.*, Hepatogastric ligament.

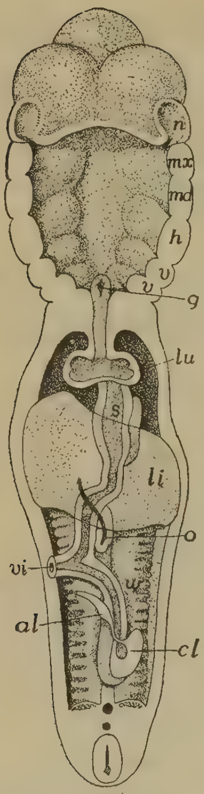

Fig. 428.

Reconstruction of the digestive canal of man. *al*, allantoic stalk; *cl*, cloaca; *g*, glottis; *h*, hyoid arch; *li*, liver; *lu*, lung; *md*, *mx*, mandibular and maxillary arches; *n*, nasal pit; *o*, omphalomesenteric vein; *s*, stomach; *v*, visceral arches; *vi*, vitelline stalk; *w*, Wolffian body. (From Kingsley after His).

pharynx and **stomach.** The former is a funnel-shaped enlargement at the cephalic end with several pairs of lateral diverticula called the **pharyngeal pouches.** These pouches in some animals break through to the outside of the body to form slits (Fig. 295). The stomach may be of many shapes and sizes in the various animals. That portion of the stomach that meets with the oesophagus (the narrow tube connecting pharynx and stomach) is known as the **cardiac** portion, while the caudal opening of the stomach is called the **pylorus** (Fig. 438). It will be found that this pyloric end is rather thick and tough. There is a valve here which closes so that the stomach can be converted into a closed sac. A rather thick short portion of the intestine immediately caudal to the pylorus is known as the **duodenum.** Then follows the **small intestine,** varying in length in all the animals, which ends in the large intestine, and this in turn connects directly with the anal opening to the exterior of the body or in a terminal enlargement which quite often receives the openings of the urinary and reproductive systems before connecting with the anal opening. In such cases as the latter the thickened portion of the large intestine is called the **cloacal chamber,** or simply the **cloaca.** (Fig. 426, III.)

In fishes, amphibians, and sauropsida, the cloaca is an important structure. In none of the mammals except the montremes does it appear as a distinct organ.

There are various important diverticula of various shapes thrown out along the digestive tract. The lateral pharyngeal pouches have already been mentioned. In fishes one often finds quite numerous **pyloric caeca.** In mammals at the beginning of the large intestine where the small one enters it there are **colic caeca.** In man as well as in several other forms of mammals one of these little blind sacs is called **the appendix vermiformis.** In birds one finds **cloacal caeca.**

DETAIL STUDY

The **pharynx** is that open portion behind the nose and mouth in mammals which extends down to the voice box. From there downward (including the **voice box**) the open portion is called the **larynx.**

There are two general types of mouth forms. The first is found in the great group of **Cyclostomata** (cycle mouths). There are no true jaws (Fig. 422). The mouth is round and cannot be closed. Examples of this form are the **lampreys** and **hagfishes.** This type of mouth is called **suctorial.** The cyclostomata are the only vertebrate parasites known. They attach themselves to a living fish and suck their way directly through the muscles of the host.

The second type of mouth belongs to that group called the **Gnathostomata** (jaw-mouths). This type of animal has movable bones or cartilaginous jaws, usually possessing teeth formed of dentine and underlaid with enamel. The jaws are developed from one pair of visceral arches. The teeth are quite similar to the placoid scales of certain fishes which have been modified in various ways. There are two theories held in regard to the **Gnathostomata** or jaw-mouth fishes. First, that the mouth is like that of the cylostomes, to which the gill arches with their associated teeth have been added; and the second, that this jaw-mouth is a **new opening** which originally consisted of a pair of gill-slits which later became fused in the mid ventral line, the first mouth then being lost. Probably the latter view has more supporters, because in the selachians, where there is supposed to be a more primitive condition, the jaw-mouth is not at the extreme cephalic end of the animal, but on the **ventral side** with a long rostrum extending cephalad to it. Later, in some of the ganoids this jaw-mouth has a **secondary position** at the very tip or terminal end.

The **pharyngeal pockets** develop from a row of outpushings meeting a similar set of inpushings from the outside (Fig. 295). If the point of contact is broken through, as in fishes, such openings are called **gill-slits.** These are **four to eight** in number which permanently form a communication between the pharynx and the exterior, thus allowing the escape of water taken in by the mouth for use in breathing.

One or more of these slits appear in the early stages of amphibians and in a few forms persist throughout life. In reptiles, birds, and mammals, there are similar inpushings and outpushings during the embryonic period, but only two or three contact-points ever form openings, and then only for a short time. However, the most anterior of these which appears in the selachians as the **spiraculum** or blow hole, persists in all higher vertebrates as the **Eustachian tube and the greater part of the middle ear.** The other pouches disappear, although cartilages, muscles, arteries, and glands arise in the embryo in connection with these pouches.

Sometimes there is an arrested development so that an open communication persists between the pharynx and the exterior of the jaw either upon one or both sides, as a **cervical fistula.** This is supposed to be a **permanent gill-slit** that for some mechanical or chemical reason has not continued growing as it normally does in the higher forms.

The nasal cavities in fishes lie above the stomato-pharyngeal cavity and are unconnected therewith, while in the amphibians (Fig. 339) there develops a pair of openings called the posterior-nares or **choanae** connecting these two portions by openings in the roof of the mouth. This communication is supposed to be "one of the changes inaugurated during the transition from water to land and allows the ingress and egress of air to the pharynx and then to the lungs without opening the mouth, since this action, although harmless for an animal immersed in water, would soon cause the drying up of a mucous membrane lining a mouth cavity if resorted to in air with anywhere near the same frequency. In the case of the nasal cavities this is prevented in part by the small size of the external openings, but still more by the formation of slime glands capable of producing an abundant secretion. The waste lacrimal fluid diverted from the eyes to the nose is undoubtedly also of assistance in this respect."

There is a tendency in the pharynx to form diverticula in the median line (Fig. 426), that is, there is here an expansion into large sacs or reservoirs which may or may not remain in communication with the pharynx itself. The air-bladders in fish are examples (Fig. 441). While this air-bladder is usually a closed sac filled by gases extracted from the blood, in a few animals one finds a rather small air-duct coming from these air-bladders to the pharynx. In fishes, where this occurs, the animal comes to the surface of the water and makes a snapping or swallowing movement. In the higher forms of animals this develops into the **pulmonary system,** the **lateral sacs being the lungs and bronchia** and the **median duct, the trachea.** The opening of the trachea into the pharynx is called the glottis (Fig. 428), which together with the various cartilages and muscles derived from the visceral system, forms the larynx. While there are always two lungs in lung-breathing animals there is only one air-bladder in those forms of vertebrates which are not lung breathing. Then, too, the air-sac or air-bladder is almost always **dorsal to the pharynx,** while **the lungs lie ventral** to it.

The flat plate of bone forming the roof of the mouth and thus separating the nasal cavities from it, is called the **hard palate.** The soft cover of this bony plate which extends backward beyond the palate is known as the **soft palate** or **velum palati.**

Just as one can easily see the **sulcus** (   ) in the median line immediately under the nose, so, in looking into the mouth, a **ridge** will be seen which is formed right through the center of its roof. As the human being, as well as all of the higher forms of animals, is bilaterally symmetrical, and as different portions of the jaw begin their growth from distinctly separate centers, which then grow toward the midline and unite, one can readily understand not only why the ridge is formed on the roof of the mouth but also why there is a **sulcus** immediately below the nose on the outer upper lip. If, due to a mechanical or chemical obstruction of some kind, the two lateral portions of palate or upper lip do not meet, a **harelip** and **cleft palate** result.

In some birds the two halves of the palate never unite. In some mammals, such as the cat and dog, the two portions forming the upper lip have not united as well as they have in the human being, and, consequently, a deep median groove called the **philtrum,** remains. This line can be seen to run along the entire **septum** of the nose externally.

Next in order of study come the **teeth, tongue, tonsils, glands of the mouth cavity,** and **glands of the pharyngeal pockets.**

There are two types of teeth which have no relationship to each other in their origin. The **true teeth are akin to placoid scales** (Fig. 429). They arise by a calcareous secretion at **the junction where ectoderm and mesenchyme meet** and are thus **a product of both layers**

The other type comes purely and simply from the cuticle and is formed by what is known as **cornification or hardening of the epithelium** (Fig. 422, 6). The parts which have invaginated to form the stomatodeum retain the capacity to form hard structures, consequently, any portion of the mouth-walls may secrete scale substances. It is necessary to appreciate this in order to understand that in the different types of fish and amphibia, teeth of almost any number, size, and shape

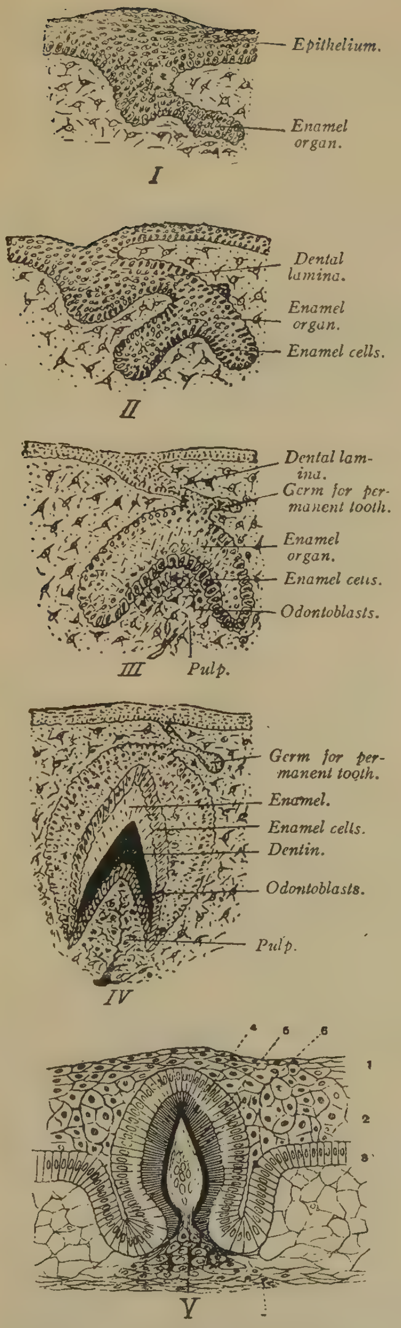

Fig. 429.
I, II, III, IV, Diagrams of developing tooth (After Hill).
V, Section through the skin of an Elasmobranch showing formation of a dermal spine. Highly magnified.
1. Horny layer of ectoderm. 2. Malpighian layer. 3. Columnar cells of ectoderm secreting. 4. Enamel. 5. Dentine (black). 6. Dentinal pulp. 7. Connective tissue. (From Shipley and MacBride).

may be found wherever there is cartilage or bone to hold them. In the higher forms of animals, in fact, in all the amniotes, with the exception of some squamata, teeth are found only on the margin of the jaws. Turtles and all present forms of birds are toothless, though many extinct birds, of which fossil remains have been found, did have teeth. It is interesting to note that even in turtles and birds that have no teeth, the **dental ridge** in which the teeth of toothed animals do develop, is nevertheless present in the embryonic stages, it being assumed that this is proof of their descent from toothed ancestors.

It will be observed in Figure 429 that at first **ectoderm thickens.** The layer of cells immediately beneath the ectoderm pushes downward into the mesenchyme. These latter cells by multiplying rapidly, push portions of this ingrowing plate of cells back up and form a sort of finger-like projection covered by the plate it has pushed before it. The **mesenchymal** finger-like projection forms the **pulp** of the tooth, while **the plate of cells which covers it** becomes what is known as the **enamel organ.** The pulp forms several layers of cells, the outer ones becoming **odontoblasts,** so called because it is from these that the bone-layer-substance **dentine or ivory** of the tooth is formed. This latter substance is a **secretion** from the **ends of the odontoblasts** and it is this which causes it to be somewhat prismatic in form.

At the base of the enamel organ a denser substance called **enamel** is secreted. This fits like a cap over the top and sides of the dentine. The dentine continues to grow and forces the tooth up through the epithelium so that the tip or crown then comes into position for use. The nerve supply of the tooth comes from branches of the **trigeminal or fifth cranial nerve.** Both nerves and blood vessels enter through the base of the tooth. Usually, as soon as the teeth are fully formed, the odontoblasts cease growing. However, there are exceptions to this rule. The tusks of elephants and the incisors of rodents function through life and therefore continue to grow.

In mammals an additional layer of **modified bone, the cement,** is formed around the root of the tooth. It may even extend through the crown. The teeth in the mouths of skates and some other elasmobranchs are arranged very much like the scales on the surface of the jaw, that is, in groups of five. In most of the vertebrates there is a succession of teeth.

Some animals, such as the shark and turtle, continue to renew and shed their teeth. Such teeth are called **deciduous.**

In mammals a **second set** of teeth usually arises directly behind or above and below the first set, so that the ends of the second set, which are to force their way through the jaw, push against the roots of the teeth which are already in use.

The group of first teeth which is formed in man is called the **milk dentition.** The second is known as the **permanent dentition.** In some mammals such as the monotremes, sirenians, and cetacea, there is only one dentition, while in some groups there are an indefinite number of successive dentitions. In such animals as Guinea pigs, and in some bats, the milk dentition is lost even before birth.

Practically all fishes with few exceptions have teeth, and these extend not only to the lining bones of the mouth, but in some even to the hyoid and branchial arches. These latter are known as **pharyngeal teeth.**

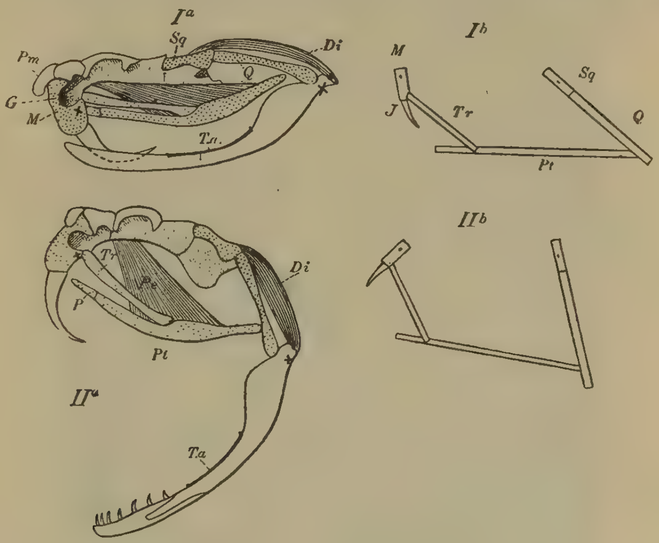

Fig. 430.

Biting mechanism of the rattlesnake. *Ia*, and *Ib*, position of the apparatus when mouth is shut. *IIa*, and *IIb*, position of the apparatus when mouth is opened widely, showing the spheno-pterygoid muscle (*P.e.*) contracted, the pterygoid (*Pt*) pulled forwards, the transverse bone or ectopterygoid (*Tr*) pushing the maxillary (*M*) rotating it and thereby causing the poison-fang (*J*) to assume an upright position. *Di*, Digastric muscle, the contraction of which lowers, or opens the lower jaw; *G*, the groove or pit characteristic of the Crotaline snakes; *J*, poison fang; *M*, maxillary; *P*, palatine; *P.e*, spheno-pterygoid; *Pm*, premaxillary; *Pt*, pterygoid; *Q*, quadrate; *Sq*, squamosal; *T*, *a*, insertion of the anterior temporal muscle, by contraction of which the mouth is shut; *Tr*, transversum or ectopterygoid; *X*, origin and insertion of a muscle and a strong ligament, contraction of which draws the maxillary and its tooth back into the position of rest and assists in shutting the mouth. (After Gadow.)

The teeth may be **cone shaped or flat,** sometimes they even form large plates as though a number of primitive teeth had grown together. Teeth may be **anchylosed** to the summit of the jaws, attached to their inner side, or have their roots implanted in grooves or pockets as in the human being. **The grooves** in the jaw, in which teeth grow, are called **alveoli.***

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*Mammals are said to be *monophyodont* if they develop only one set of teeth, and *diphyodont* if they develop two. However, even in momophyodont mammals, a second set usually develops, although this set later becomes absorbed or remains in a vestigial condition.

When all the teeth are uniform they are said to be *homodont*, while if they vary in shape they are *heterodont*.

Teeth are said to be *acrodont*, if anchylosed to the summit of the jaws, *pleurodont*, if fastened to the jaw's inner side, and *thecodont*, if the roots are implanted in alveoli.

Teeth have also received names according to their function or their peculiar physical appear-

The poison fangs of certain serpents are really specialized teeth on the maxillary bones. They may be permanently **erect, or turn as on a pivot,** so that when the mouth is closed the teeth lie along the roof of the mouth. Vipers and rattlesnakes are examples of this latter type. (Fig. 430.)

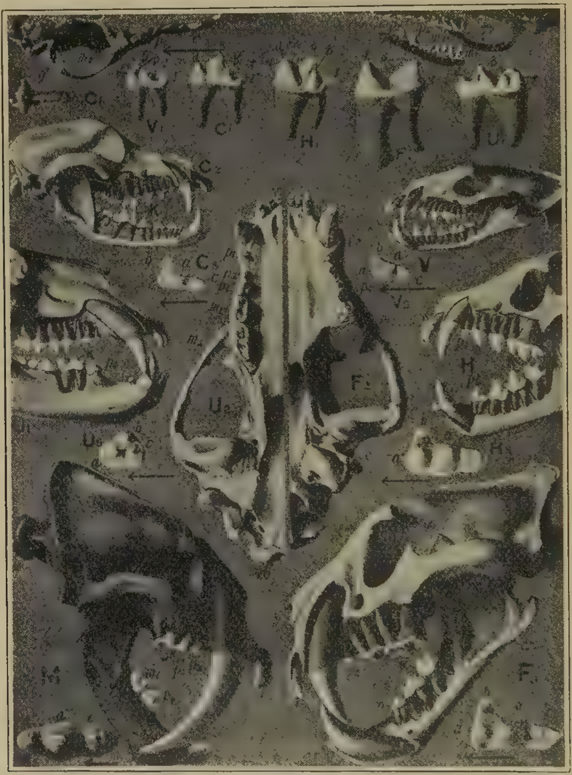

Fig. 431.

The types shown have been chosen from the principal families of the Carnivora in such a manner as to present a complete view of the changes in dentition in that order. They are:

P, *Proviverra* (*Cynohyaenodon*) *Cayluxi* (*Creodonts*); V, *Viverra* (*Civets*) (*Viverridae*); H, *Hyaena crocuta* L, (*Hyaenidae*); F, Felis leo L. (lion) (*Felides*); M *Michairodus cultridens Cuvier* (Ancient saber-toothed tiger of the Tertiary age) (*Felides*); C, *Canis familiaris L.* (common dogs) (*Canides*); U, *Ursus arctos, L,* (Bears) (*Ursides*).

Letters used in common for the figures of the groups of teeth: *i,* incisors; *c,* canines; *p,* pre-molars; *m.,* molars; *k,* carnivores; *cm,* inferior maxillary condyle; *gl,* glenoid fossa; *co,* occipital condyle.

I. *CREODONTS.* Extinct order of the Eocene and of the lower Oligocene; supposed to be the common stem of all the carnivora.

Type form: *Proviverra* (*Cynohyaenodon*) *Cayluxi Filhol,* of the phosphorite of Quercy (upper Eocene and lower Oligocene).

P—Right half of the base of the skull seen from below. Below, fragment of the right half of the lower jaw, internal aspect.

Complete Dental Formula $\frac{3}{3}\ \frac{1}{1}\ \frac{4}{4}\ \frac{3}{3}$

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ance. For example, they are said to be *secodont,* if used for cutting purposes, such as those of cats; *bunodont,* if used for crushing as in man; *lophodont,* if they possess well-marked transverse ridges as in the elephant; and *selenodont* when they possess longitudinal crescent-shaped crests as in the horse.

Premolars becoming complicated from before backward, to pointed tuberosities, and compressed laterally (secodont type); the fourth premolar (p_4) and the three upper molars united to three tuberosities by sharp ridges. On the lower jaw, these teeth present the entire anterior surface to three pointed tubercles and a flattened posterior heel (Type: tuberculo-sectorial of Cope).

II. *CARNIVORA.* They are distinguished from the Creodonts, from the point of view of dentition, by the differentiation in the two jaws, of a carnassial, or tooth of slicing action, made apparent by its greater development than that of the other molars. It is the 4th premolar of the upper jaw; in the lower jaw it is the 1st molar.

In a general manner, all the teeth placed before the carnassial, that is to say all the premolars, are sharp-pointed; all those which are behind it are tuberculated.

1. *Viverrides* (*Civets*): The most primitive of the Carnivora properly speaking (true Oligocene), from which all the other forms are usually considered to have been derived. Type shown: *Viverra indica Desm.*

V, skull, seen from the right side. The maxillae have been dissected away sufficiently, as in the other figures, so as to show the roots of the teeth.

Vs, left superior carnassial tooth, seen from the crown.

Vi, left inferior carnassial, seen from the internal aspect.

Dental formula $\frac{3}{3}\ \frac{1}{1}\ \frac{4}{4}\ \frac{(3)}{(3)}\ \frac{2}{2}$

The number of molars is in general reduced to two, characteristic of a carnivorous specialization.

2. The *Mustelids* (marten, sable, polecat, weasel, stoat) are very close to the primitive type. The carnivorous tendency is strongly developed, as shown by the great reduction of the molars and the higher development of the carnassial tooth.

Starting from the *Viverrides*, the various forms of the carnivora show changes in two clearly divergent directions: one, in which the meat-eating nature of the animal becomes more and more evident, as in *Hyaenidae*, *Felides*, and *Pinnipedes* (seals, eared seals, walrusses) and the other which returns somewhat to the omnivorous order, separated from the *Hyaenidae* and *Felides*, and giving rise to the *Canides* and *Ursides*.

3. *Hyaenides*: These form a branch supposedly derived in a direct line from the *Viverrides* (*Hyaenictis*) as they appear in the upper Miocene.

Type Figure: *Hyaena Crocuta L.*

H, the two jaws, seen from the left side.

Hs, left superior carnassial tooth, seen from the crown.

Hi, left inferior carnassial tooth, internal view.

Dental Formula: $\frac{3}{3}\ \frac{1}{1}\ \frac{4}{3}\ \frac{1}{1}$

dentition quite like that of *felides*, and not well developed in a carnivorous sense.

4. *Felides* (cats): The most characteristic of the *Carnivora*. Their most typical representatives appear in the Miocene type, but they are preceded by others, which connect them with the *viverrides*.

Type Figure: The lion (*Felis Leo L.*); *Machairodus cultridens Cuvier*, (a fossil Feline of the European Pliocene age).

F_1, Skull of a lion, seen from the left side.

F_2, Left half of the same skull, seen from below.

F_3, Left superior carnassial, seen from the crown.

Fi, Left inferior carnassial, seen from the internal aspect.

Dental Formula $\frac{3}{3}\ \frac{1}{1}\ \frac{3}{2}\ \frac{1}{1}$

Of the tuberculated molars, a single one persists, very much reduced (m_1). The premolars, although secondont, have undergone a certain reduction in their number as well as in their size, leaving all the functional importance to the carnassials, which have become enormous. The canines are likewise very strong, and are much longer than their neighbors. On the other hand, the incisors, whose cutting function is done much more efficiently by the carnassials, have diminished. The jaw is, all in all, greatly shortened. Notice also the great development and widening of the zygomatic arch, giving a large surface for the levator muscles of the lower jaw (the temporalis, which passes under the arch, and the masseter, which takes its origin from the entire length of the arch). It has thus acquired considerable size and strength. The lower jaw is greatly hollowed out on its external aspect, to permit insertion to the fibers of the large masseter muscle.

M, Skull of *Machairodus cultridens* (extinct saber-toothed tigers), seen from the left side.

Ms, left superior carnassial, seen from the crown.

An exaggeration of the Feline type.

Dental formula $\frac{3}{3}\ \frac{1}{1}\ \frac{2}{1}\ \frac{0}{1}$

Huge development of the superior canine teeth, which surpass so far those of the lower jaw that they limit closely, on each side, the buccal gap, no longer permitting free use of the canines and carnassials in tearing off meat.

5. *Canides* (dog-like carnivora). A mixed group, both meat-eating and omnivorous. The canides appear early in the Oligocene, their first forms being closely related to the primitive *Viverra* or to the *Creodonts*, some of whose characteristics are even more primitive than those of the typical *Viverrides*. The dog family appears in the early Pliocene.

Type Figure: *Canis familiaris, L.*

C, Left half of the skull, seen from below.

C', Left inferior maxillary condyle, seen as a horizontal cylinder (characteristic of all the *Carnivora*) in relationship with the glenoid cavity which is hollowed out cylindrically.

C_2, The skull, seen from the right side.

Cs, Left superior carnassial, seen from the crown.
Ci, Left inferior carnassial, seen from the internal aspect.

Dental formula: $\frac{3}{3}\ \frac{1}{1}\ \frac{4}{3}\ \frac{3}{3}\ \frac{(2)}{}$

6. *Ursides* (Bears). The least carnivorous of all the Carnivora. They originated, apparently, in the upper Miocene, from the primitive *Canides* (*Amphicyon*).

Type Figure: *Ursus arctos* L.
U_1, The two jaws seen from the right side.
U_2, Left half of the base of the skull seen from the lower aspect.

This figure has been placed near the corresponding figure of the Lion in such a manner as to render apparent the comparison between these two extreme types. The comparison must be limited to the portion included in each figure between the incisive teeth and the occipital condyle (*co*). Behind this there is a very large hollowed out area which projects from the posterior aspect, to serve as the inservation of the posterior muscles of the skull and neck.

Us, Left superior carnassial, seen from the crown.
Ui, Left inferior carnassial, seen from the internal aspect.

Dental Formula: $\frac{3}{3}\ \frac{1}{1}\ \frac{3}{2}\ \frac{2}{3}$,

This is probably a regressive adaption to the omnivorous regime. The enormous development of the molars have become quadrituberculated and complicated by the appearance of little tubercles on or between the greater tubercles. Regression of the cutting function of the teeth has followed, the flesh-eating character becoming hardly apparent except in the remarkable power of the upper canines, with their very oblique insertion and long root. The skull also lengthens.

Changes which take place in the Superior Carnassial Teeth: (Figs. *Vs, Hs, Fs, Ms, Cs, Us*. In the figures the arrow indicates the upper teeth, the arrow's point being directed toward the opening of the mouth).

a, paracone or antero-external cusp; *a'*, anterior accessory cusp; *b*, protocone, or antero-internal cusp; *c*, metacone, or postero-external cusp.

Primitive form (*Viverra, Vs*); type trigodont (triconodont). The tooth contains two external cusps (*a,c*) compressed laterally and united in a single cutting edge, and a third tubercle (*b*) placed anterior and forward. A fourth tubercle (*a'*) is often found in front of the two external cusps on the same line with them. The cutting edge formed by these last is lengthened in such a manner as to place these tubercles together and thus present three points. The tooth has three roots, two anterior and one posterior.

Hyaenidae and *Felides* (*Hs* and *Fs*): The external cutting edge is developed highly in these. The internal anterior tubercle remains conical and blunt, but disappears completely in *Machairodus* (*Ms*).

Canides: (*Cs*): Changes in the omnivorous group. The tubercle *a'* has disappeared, the tubercle *b* remaining prominent.

Ursides: (*Us*): There is the same type of accentuation as in the *Canides*. Three conical tubercles.

Changes in the Lower Carnassial: (Figs. *Ui, Ci, Hi, Fi, Vi*). The arrows are placed above the tooth to indicate the lower ones. The point indicates the anterior direction. *a*, paraconid or anterio-internal cusp; *B*, protoconid or external-anterior cusp; *B'*, metaconid or internal posterior cusp; *Y*, hypoconid, or posterior talon.

The primitive type, (*Viverrides, Vi*) is here the tuberculo-sectorial type of Cope. It contains (1), An anterior part with three tuberculated points: two internal, *A*, *B'*, and one external, *B*, (2) a posterior talon *Y*, low and flattened, carrying one or more blunt tubercles. The tooth presents, in other words, a secodont anterior portion (carnivorous) and a tuberculated posterior portion (omnivorous). It has two roots corresponding to the two parts.

This tuberculo-sectorial type is common to all the lower molars of the creodonts and is limited more or less to the true carnassial tooth in the true Carnivora.

Canides. Ci: The tuberculo-sectorial type is preserved but with accentuation of the carnassial character. Then there is a reduction of the talon predominance of *B*, reduction of *B'*, and the anterior root is somewhat stronger than the posterior.

Hyaenidae, Hi.: Regression of the talon; the tubercles *A* and *B* compressed and united in a sharp cutting edge, and bicuspid; *B'* notably reduced. The anterior root is much stronger than the posterior.

Felides, Fi.: The talon of *B'* has nearly disappeared and there is predominance of the anterior root.

Ursides, Ui.: Omnivorous type; the secodont part is smooth; its tubercles are blunt and conical; the talon contains more than half of the crown; it is covered by the secondary tubercles, which are elevated almost to the level of the anterior cusps. The whole of the talon has this one surface entirely similar to that of the tuberculated molars which are placed next in position.

Title Figures: *P*, head of Panther (*FELIS*); *Ci*, head of Civet (*VIVERRA*). (From the charts of Rémy, Perrier & Cépède).

There are four kinds of teeth in mammals (Fig. 431). In the human being they are alike in both upper and lower jaws, as well as alike in both halves of upper and lower jaws. For classification of teeth, we use only one-half of the teeth in either jaw. Thus in man we find the two teeth nearest the midline—the **incisors**—are followed by **a single canine**. This is distinctly cone shaped and has a single root. Back of this come the **two pre-molars** commonly called **bicuspids**, having two roots and complicated crowns. They appear both in the milk and permanent dentitions; and lastly **three molars** quite like the pre-molars in form, with several roots, but appearing only in the permanent dentition. The number and kind of teeth is expressed by what is known as a **dental formula.** As already stated, **the number and kinds of teeth in the two halves of the jaw are the same,** so only one side need be represented in the formula, but, as **in some animals the upper and lower jaws do not have the same types and forms of teeth,** the formula must take both upper and **lower jaws into consideration.** The upper figures, therefore, represent one-half the upper jaw and the lower figures one-half the lower jaw.

DENTAL FORMULA

$$i\frac{2}{2},\ c\frac{1}{1},\ pm\frac{2}{2},\ m\frac{3}{3}$$

This is the dental formula for man; that for the opossum being:

$$i\frac{5}{4},\ c\frac{1}{1},\ pm\frac{3}{3},\ m\frac{4}{4}$$

EPIDERMAL TEETH

Epidermal teeth occur in cyclostomes (Fig. 422, 6) and various larval stages of amphibia and monotremes. In the cyclostome these are little cone-like projections of cornified epithelium with an underlying core of integument. These epidermal teeth are differently arranged in the lampreys and myxinoids. "In the latter they are few, there being a single tooth on the palate and two chevron-shaped rows on the top. In the lampreys, nearly the whole inner surface of the oral hood is lined with these teeth of varying shape and there are a varying number upon the tongue. These teeth are used as a means of fastening the animals to their prey and those of the myxinoid tongue are used for boring into the fishes on which those animals feed. In the larval anura (Fig. 318), the edges of the jaws are armed with **cornified papillae** serving as teeth, the arrangement of which varies in different genera. They are frequently aggregated in dental plates used in scraping the algae from submerged objects. They are not related to the teeth of cyclostomes."

Baleen or whalebone should be mentioned here. This is formed in large plates of horny material attached to the margins of the upper jaw (Fig. 392). The fringed ends and edges of these plates serve as strainers to extract the food products from the various materials taken in with the water.

In the embryos of certain lizards and snakes there is a **median tooth** which projects from the mouth and which is used to rupture the egg cell when the young is ready to escape. Such a tooth is called **an egg-tooth.** An egg-tooth is formed in the turtles, **Sphenodon,** crocodiles, birds, and monotromes, but in these cases it is only a thick (sometimes calcified) portion of the epidermis.

THE TONGUE

The tongue varies to a very considerable extent in the different groups of vertebrates (Fig. 432). In mammals the **hyo-branchial support** consists simply of a **basi-hyal** (body) and two pairs of **horns** (cornua). The most cephalad pair are the longer and usually consist of four bony structures, the **cerato-hyal,** the **epi-hyal,** the **stylo-hyal,** and the **tympano-hyal,** the latter bone attached to the skull in the tympanic region. The pair of horns lying caudal consists of only a single skeletal piece of bone known as the **thyro-hyal** which connects the body with the thyroid cartilage of the larynx. In the human being, the anterior or cephalad horns are considerably modified from those in other mammals.

The tympano-hyal and the stylo-hyals have fused with the **otic region** of the skull to form the **styloid process,** while the hypo-hyal is a mere rudiment connecting with the styloid process by a ligament; the cerato-hyal is not present. The anterior horns, though typically longer and more complex than the others, are called the "lesser" in man, because the earlier anatomists took all of their names from the human being without any comparisons with other forms.

There is **no functional tongue in fishes,** although the material which develops into a tongue in the higher forms is present. This is known as the anterior part of the **hyo-branchial apparatus.** The part of this complex apparatus lying most cephalad, is found in the floor of the mouth cavity. It is naturally shaped according to the outlines of the jaw which border it. It may even be pushed forward so as to form a slight elevation by the action of the visceral muscles.

In amphibians where the gill-bearing function has more or less ceased, this region forms the **basis of the tongue,** while a fleshy organ of **some kind** may develop.

In the higher forms of vertebrates **two to four of the visceral arches form the skeletal basis of the tongue.** The **hyoid arch is the structural foundation to which the muscles of the tongue are attached.** Here one usually finds, although there are many varieties, a **median basi-branchial piece** called the **os entoglossum** and two caudad projecting horns—the **cornua.** In **Sauropsida** the tongue is a direct condition of this, and the principle motion consists in protruding and withdrawing the entire organ by means of the two caudal horns which lie in sheaths from which they may be everted. The tongue is sometimes quite long and then the sheaths and the enclosed horns are, of course, of corresponding length. If they are very long there must be some disposition made of them when retracted. This is interestingly observed in the salamander **Spelerpes fuscus,** where the sheaths of the horns run down the sides of the body until they are attached to the pelvic bones, the ilia. In the woodpecker they pass around the occipital region over the top of the head and end near the anterior nares of the base of the upper beak. In such cases the ends of the horns are fastened to the bottom of the sheaths so that the sheath is turned inside out when they are withdrawn.

The tongue develops between the hyoid and mandibular arches (Fig. 432). The hyoid often extends into and supports the tongue. Consequently, the organ itself cannot be moved unless its supporting skeleton is likewise moved. The tongue is a **sensory organ** but can be used as an **organ of touch and taste.** There are little elevations (Fig. 433) known as papillae, in many if not most animal tongues. Some of these are sensory while others have become hardened and serve as rasping organs.

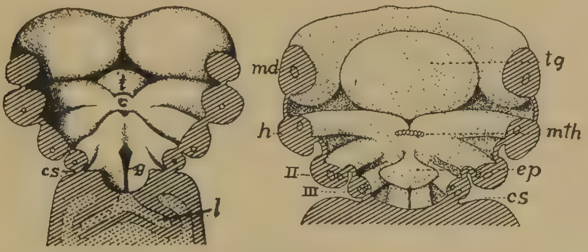

Fig. 432.

Two stages in the development of the tongue and pharyngeal floor of man. *c*, copula (basihyal element); *cs*, cervical sinus; *ep*, epiglottis; *g*, glottis; *h*, hyoid arch; *md*, mandibular arch; *mth*, median anlage of thyroid gland; *t*, tuberculum impar; *tg*, tongue. (From Kingsley after His.)

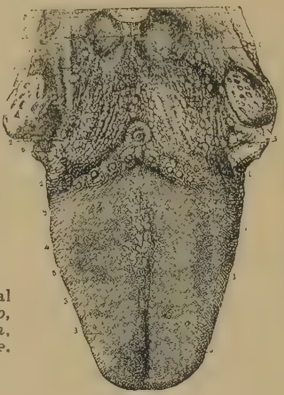

Fig. 433.

Papillary surfaces of the human tongue showing fauces and tonsils. 1, 1, circumvallate papillae, in front of 2, the foramen caecum; 3, fungiform papillae; 4, filiform and conical papillae; 5, transverse and oblique rugae; 6, mucous glands at the base of the tongue and in the fauces; 7, tonsils; 8, part of the epiglottis; 9, median glosso-epiglottidean fold (frenum epiglottis). (From Hill after Sappey.)

In the cyclostomes the tongue is thick and fleshy and is supported by a cartilaginous skeleton. The muscles which throw out the tongue are called **protractor muscles** and those which draw the tongue back to its normal position are known as **retractors.** These muscles are developed from the **postotic myotomes** and their nerve supply comes from the **hypo-glossal nerve.** In the myxinoids the **terminal end** of the tongue possesses **epidermal teeth** which thus form a boring organ by which these animals obtain entrance into their prey. In the lampreys the surface has a rasping organ and also forms part of the sucking apparatus. In the amphibians, there are a few anura (aglossa), in which the tongue is practically absent, but in most of them the tongue actually contains intrinsic muscles supplied by the hypo-glossal nerve and in such case the tongue can be moved quite readily. The tongue of amphibians is made up of a small basal portion quite similar to that of the fish, but to this is added a large glandular part which develops between that portion called the **copula or medial region** and the lower body. The amphibian tongue secretes slime which is rather useful in capturing its prey. In the anura the tongue is fastened to the margin of the jaw, while its free end when not in use lies on the floor of the mouth. In urodeles a much greater portion of the tongue is attached than in anura, where not only the anterior margin of the tongue, but a part of the ventral surface as well, is held quite definitely in place by attachments.

The supporting skeleton of the tongue, as mentioned above, usually consists of two pairs of horns largely formed from the ventral ends of the hyoid and first branchial arches. The median portion or body which unites these horns is known as the **copula.** The reptilian tongue includes the parts already mentioned which are found in the amphibia, and in addition a median growth which arises between the basi-hyal and the lower jaw known as the **tuberculum impar** (Fig. 432, t). Added to this, there is found a pair of **lateral folds** lying above the first visceral (mandibular) arch. From now on, as these parts develop, the **trigeminal nerve sends twigs to the tongue in addition to the hypoglossal and glossopharyngeal as in the lower groups.** In turtles and crocodiles, the tongue lies on the floor of the mouth and cannot be protruded. In reptiles possessing a **retractile tongue,** the hyoid apparatus extends into that organ. The unpaired cephalad portion which we have called the **os entoglossum** is equivalent to the term **copula** or **basi-hyal**; the **retractor** muscles are usually attached to the two horns. In the tongues of birds, the lateral parts of the reptilian tongue are not to be found and consequently there is no branch from the trigeminal nerve. It is to be remembered that during the development of a part, the nerves **follow** the growing muscle. The bird's tongue has **no intrinsic muscles.** It has many varieties of form, but is usually slender and covered with horny papillae. Even its skeleton is reduced, there being only an os entoglossum with a pair of structural elements attached in front, known as the **paraglossae,** while, on the sides, a pair of horns form the first branchial arch, and, in the median line behind, there is a portion called the **urohyal.** This is well marked in the woodpecker, as has been stated.

Now, as to the use of the tongue. With the exception of the whale the tongue is very mobile in all forms of mammalian life. The mobility reaches its extreme in the ant-eaters (Fig. 387). It is largely due to the intrinsic muscles which have been derived to a considerable extent from the hypo-branchial musculature. The tongue itself is developed from the unpaired elevation—the **tuberculum impar,** and from two thickenings on the mandibular arch, which, together with the fleshy ridges above the hyoid arch, form the tongue. These fleshy ridges above the hyoid arch form the back part of the tongue. The line formed between the anterior and posterior parts cannot very readily be seen in the adult, but it is quite close to the **circumvallate papillae** and the **foramen caecum.** This latter is a little open place or pit in close relationship to the development of the thyroid gland.

It will thus be seen that the mammalian tongue is quite similar to that of reptiles, and exceeds that of birds by having portions in it that come from the mandibular arch.

Two views are usually stated as to the relations of the mammalian and amphibian tongue. One holds that the amphibian tongue is entirely unrepresented in the mammals, unless it be by the **sublingua.** This is a fleshy fold beneath the tongue of marsupials and lemurs, traces of which occur in other mammals, even in man, as folds **(plicae fimbriatae)** beneath the tongue. In some cases **(Stenops)** the sublingua is supported by cartilage, which may be the entoglossum. The other view is that at least the anterior part of the tongue in amniotes is quite like that of amphibia. This view holds that the **lyssa** (a vermiform mass of cartilage, muscle, and connective tissue, lying ventral to the median septum of the tongue), is the equivalent of the entoglossum and its associated structures.

The dorsal surface of the tongue is covered with a soft epithelium with many mucous glands. There are also varying forms of papillae (Fig. 433), some of which, the **taste buds** for example, are sensory, while some become cornified to form epidermal teeth. A rasping type of tongue in which many of the papillae have become cornified is that of the cat.

GLANDS

In animals that live under water it is quite natural that comparatively few glands should be found in the mouth cavity other than the very simplest kind. These pour out a slight amount of mucus. If glands were to exist there to any extent their secretionss would be washed away with the incoming and outgoing water that passes through the mouth cavity of such animals. Then, too, one can easily understand that, where a secretion of an animal gland is soluble in water, if such animal lives in water, the secretion could be of no value whatever. Contrasted to this, it can also readily be understood that animals which breathe air must have many glands moistening all surfaces constantly, or the absorption, which is always going on, would soon have all parts of our bodies so dry that they could no longer function. For this reason terrestial animals have many more secreting glands than water animals.

Mammals therefore have **salivary** glands. The saliva, which these secrete, contains not only **mucus,** but a digestive ferment known as **ptyalin** which changes starch into sugar.

Glands are named largely after the **position they occupy,** such as labial, lingual, sub-lingual, etc.

In the air breathing amphibia, snakes, and lizards, there are **labial glands** opening at the basis of the teeth as well as an **intermaxillary** or **internasal** gland, in the septum between the nasal cavities, as well as

palatal glands near the **choanae,** although these latter glands are lacking in the caecilians. There is a sub-lingual gland on either side in many reptiles. Probably all secretions from salivary glands in snakes are poisonous. There is only one known poisonous lizard **(Heloderma).** In these the sub-lingual glands furnish the poison. Birds do not have labial and internasal glands, but they do have numerous other ones which open separately into the roof of the mouth. They also have anterior and posterior sub-linguals and even sometimes **"angle"** glands at the angle of the mouth, a condition sometimes supposed to be a remnant of the labial glands in the **Sauropsida.** Mammals possess small **labial, buccal, lingual,** and **palatine** glands imbedded in the mucous membrane of the mouth, each of which opens through a separate duct. All of these glands serve to keep the various surfaces moist.

Many glands, however, have become **specialized**; for example, the **intermaxillary** glands of frogs and toads (opening into the roof of the mouth) secrete a viscid and sticky fluid which the tongue uses as it is thrown out to catch and hold insects and other moving objects. So, too, the **buccal glands** of poisonous serpents furnish the venom which is sent forth through the poison fangs. These poison fangs, it will be remembered, are **teeth,** and they are provided either with a groove along the external surface or else they have a very small lumen through the center of the tooth and act similarly to a hypodermic needle. Those glands which assist in throwing out a thin, watery lubricant are called **serous glands,** while those assisting in softening and dissolving dry food so that it can be more easily swallowed are called **salivary glands** without regard to their position.

In mammals the salivary glands are the **parotid,** lying ventral to the ear (swelling up in man when he has **mumps), the submandibular** (called **submaxillary in human anatomy),** the **sublingual,** and the **retrolingual.** This last one is closely associated with the submandibular. It is not found in all mammals.

The **serous** glands secrete a clear fluid without any salivary attribute. The **molar** gland of ungulates or the voluminous **orbital gland** of dogs are examples of this type. The orbital glands open into the mouth-cavity close to the last upper molar. The submandibular is found in the lower jaw beneath the mylohyoid muscle. Its duct **(Wharton's duct)** opens near the lower incisor teeth. The retrolingual gland is near the submandibular, its duct opening close to Wharton's. The sublingual gland lies between the tongue and the alveolar margin of the lower jaw. It empties through several ducts. The parotid opens through **Stenson's duct** near the molars of the upper jaw.

THE PHARYNX

We have already described the pharynx as the cephalic end of the digestive canal which is found between the cavity of the mouth and the oesophagus from which the respiratory system develops. It will be described in more detail in our discussion of the respiratory system. But, as there are certain more or less significant organs developed in the pharyngeal region, it may be well to discuss them at this point. These are especially the **thymus** and **thyroid** glands. It is customary to trace the development of these two glands from the cyclostomes upward, because the cyclostomes furnish the first (more generalized) stage of development of such glands, and thus make it possible to follow up consecutively any so-called advance from a lower developmental type to a higher one. (Figs. 294, 434.)

There are six pharyngeal pockets (except in the cyclostomes) developed on each side. Each of these pockets possesses a dorsal and a ventral recess. It is around these recesses that a group of epithelial cells develops an organ-anlage, all seemingly alike in the lower forms. In the higher forms, however, the dorsal group soon forms the **thymus** and the ventral forms what are called epithelial corpuscles.

These thymus-anlagen may separate from the layer where they originated or they may fuse into a single elongated organ, or they may become constricted in number, the anterior ones disappearing.

In the cyclostomes, there are seven anlagen. In the teleosts there are six pharyngeal pockets, but only four anlagen, and these are all the more posterior ones.

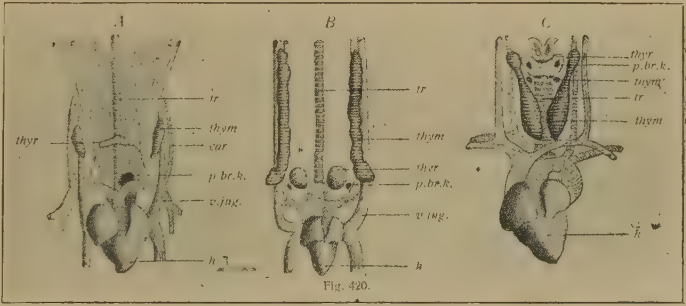

Fig. 434.

Thyroid and thymus glands with closely related organs. A, *lizard;* B, *Hen;* C, *Calf.* *car,* carotid artery; *h,* heart; *p.br.k.,* postbranchial bodies; *thym,* thymus; *thym',* point of thymus attachment; *thyr,* thyroid gland; *tr,* trachea; *v.jug.,* jugular vein. (After DeMeuron.)

In the mammals it is the third pocket which produces the thymus-anlage, although sometimes there is a tiny addition from the fourth.

The epithelial corpuscles tend to disappear, but in amphibians they become glandular and associate with the carotid artery to form **carotid glands.** The number of these carotid glands varies in different groups of animals.

Immediately behind the last gill slit, in the floor of the pharynx, there is a pair of evaginations. These have been termed **suprapericardial**

cardial bodies because they secondarily become associated with the pericardium of the selachians. At present they are usually called **post-branchial bodies.** In selachians a complete pair of these bodies develops, but in urodeles and lizards only the **left one** ever completes its development, the right ultimately disappearing. Whether these bodies occur in birds and mammals is not known, although there are somewhat similar growths which are called **parathyroid bodies,** which do develop in these animals and then become lost in the lobes of the thyroid gland.

Explanations of these bodies are not yet satisfactory.

The thyroid has come to be considered a very important organ since **endocrinology** looms up so large in the medical world. This gland is an evagination of the pharynx. It is first seen in the selachians, but makes its appearance regularly in the higher forms. It arises from the floor of the pharynx at about the level of the interval between the first and second pockets. It becomes compact, and, like the thymus, does not develop a duct. In the larva of **Petromyzon** (one of the cyclostomes) the thyroid appears as an open trough, lined with cilia, which is in open communication with the pharynx, a position quite like that in **Amphioxus.** This trough is called the **hypo-branchial groove** or **endostyle,** an organ which assists the passage of food down the pharynx by exuding a slimy secretion and by furnishing a definite track, with cilia, which can thus facilitate its movement.

Professor Wilder thinks the thyroid gland is primarily a digestive organ, though in the true vertebrates its structure, as well as its function, has nothing to do with digestion. It is now generally taught that the internal secretions of the thyroid gland stimulate growth and inhibit development, while the secretions of the thymus gland stimulate development and inhibit growth.

THE OESOPHAGUS

This is the swallowing tube connecting the mouth with the stomach. It lies directly against the interior of the dorsal wall of the body-cavity and thus lacks a serous coat. There are no digestive glands in its walls as a rule. Its length quite naturally varies with the length of the neck of the animal in which it occurs. Usually, its internal lining is a smooth epithelium. In the chelonians one finds cornified papillae pointing backwards. The oesophagus, like other parts of the digestive tract, consists of five layers; however, as it will be remembered that the ectoderm has indented to form the anterior and posterior openings into the digestive tract, a histological examination in the region where these two divisions merge into each other will show a change of structure.

The muscles contained in the walls are striated at the cephalic end and extend back in some cases even into the stomach. The oesophagus usually has the same diameter throughout, but in many, if not most birds, there is a dilation called the **crop** or **ingluvies.** This may either be an expansion on one side, or, as in pigeons, it may consist of median as well as a pair of lateral chambers. The crop may be a simple reservoir for food, or it may be a real glandular organ where secretions are poured forth and digestion started. In fact, during the breeding season pigeons secrete a milky fluid here which is used in feeding the young.

THE STOMACH

The various portions of the stomach have already been named and described in the frog. To the terms there given, should be added the **small curvature** at the top or anterior surface of the stomach, usually called the **"lesser"** curvature, and the posterior curvature called the **"greater."**

In some forms of animals such as amphibians, the lining of the mouth, oesophagus, and stomach is covered with cilia. In birds the stomach is divided into an anterior glandular region called the **proventriculus,** and a posterior muscular region called the **gizzard.** After the food has passed through the proventricular region and has mixed with the secretion from its glands it passes into the gizzard. This latter organ is not only muscular but the muscles have developed into a pair of disks with tendinous centers. There is a secretion in the gizzard which hardens the lining sometimes, even raising little elevations which are used in grinding the food. One might almost consider them teeth. Remembering that birds have no true teeth, one can readily understand the advantage such an animal has in a gizzard of this type. Grain-eating birds swallow small pebbles which enter the gizzard and are thus also made use of for grinding purposes.

In fact, in the fossil pterodactyl there have been pebbles "found in such portions as to lead to the supposition that these reptiles also had a gizzard." It is well to note in this regard that the grain-eating birds have the best developed gizzards, while birds of prey have gizzards much less fully developed. In one species of pigeons a part of the wall of the gizzard is ossified. In mammals there are more varying forms of stomachs. These are divided in from one to four regions. The ruminants have two well developed divisions of the stomach (Fig. 435), the **rumen** or **paunch,** and the **reticulum** or **honey comb,** though these two divisions are really enlarged portions of the oesophagus and serve as reservoirs of food. The food is regurgitated into the mouth for mastication, and after it is swallowed a second time passes into the true stomach, the **psalterium** (also called **omasus** or **manyplies),** and then to the **abomasum** or **rennet.** The latter is used for gastric digestion.

It is of interest here to trace the embryonic changes of the mesentery in mammals. The mesentery supporting the stomach is called the **mesogastrium.** The first curvature of the stomach, which is toward the left, broadens the corresponding part of the mesogastrium, an effect which is still further increased by the lateral torsion of the entire stomach. The spleen develops within this widened part and by its weight produces a fullness which in turn causes a sagging down behind (dorsal to) the lesser curvature, although attached to the greater. This tendency continues and causes the free lower fold of the bag-like extension to hang down behind the stomach (Fig. 427).

This fold is called the **greater omentum (omentum majus)**, which, as all mesenteries are essentially double, must consist of four layers of serous membranes, applied two and two, each pair holding between them the blood vessels and absorbent vessels naturally belonging to a mesentery. The cavity of the bag is the **lesser peritoneal cavity** of human anatomy, and the opening into it (behind the stomach) is the **foramen epiploicum (foramen of Winslow)**. While the bag is widely open in most mammals, in man the foramen is considerably reduced in size, and the layers forming the pendulous fold are fused together to form a four-layered apron that hangs below the stomach and covers the intestinal folds.

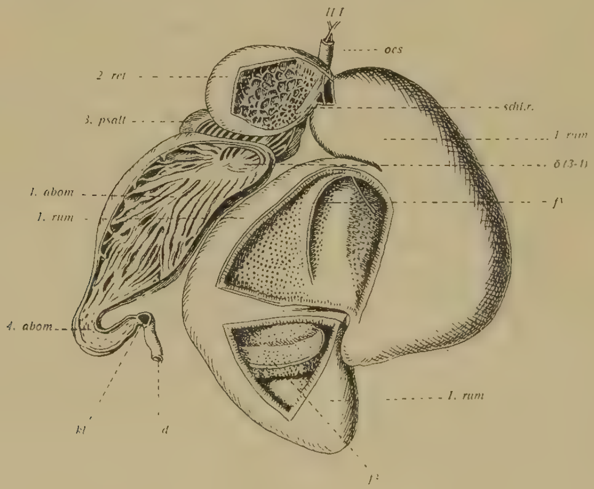

Fig. 435.

Stomach of a Sheep. 4 *abom*, abomasum; *d*, intestine; f^1,f^2, two folds which divide the rumen (paunch) into three regions; *kl*, plyoric valve; ö (3-4) opening which leads from the third to the fourth stomach region; *oes*, oesophagus; 3, *psalt*, psalterium (omasus or manyplies); 2.*ret*, reticulum (honeycomb); 1,*rum*, rumen (paunch); *schl.r.*, pharyngeal groove. The piece of wire marked *I* shows the direction the unmasticated food takes, while *II* shows the direction of the remasticated food. (After Carus and Otto.)

THE INTESTINE

The **duodenum** takes its name from the twelve inches of rather large diameter intestine which immediately follows the stomach. The word "duodenum" is a name which was taken from human anatomy though even in man it is closer to eleven inches in length than it is to twelve inches in the adult. In the lower forms of animals it varies in length and shape, as do all the other parts of the intestinal tract.

Growing from this portion of the intestinal tract, immediately beyond the pylorus, in some of the ganoids and teleosts there may be as many as one to two hundred blind tubes extending. These are known as the **pyloric caeca.** There are a few elasmobranchs which have only one pair of these caeca. These may be expanded into a pouch called a **bursa Entiana.** The region of the intestine running caudad from the duodenum is also called the **post-hepatic intestine,** and it is in this region caudad to the liver, in which most of the digestive processes. as well as most of the absorption of the products of digestion, take place.

The food having been more or less mixed with various salivary secretions, and having been reduced to a semi-liquid state. receives the bile from the liver, and the pancreatic juice from the pancreas (Fig. 436). It is then ready, after being moved back and forth by the peristaltic movement of the intestine, to be taken up and absorbed by the little finger-like processes (villi) which extend from the inner surface of the small intestine. As this has already been discussed it need not be entered into again here. It is well, however, to remember that the length of the intestine **varies with the type of food the individual eats.** It is longer in plant-eating animals than in meat-eating animals. A classic illustration of this is to compare the length of the intestine in the adult frog with that of the tadpole. The adult frog's intestine is no longer than that of a tadpole half the size a frog would be if it had kept up its relative increase in size.

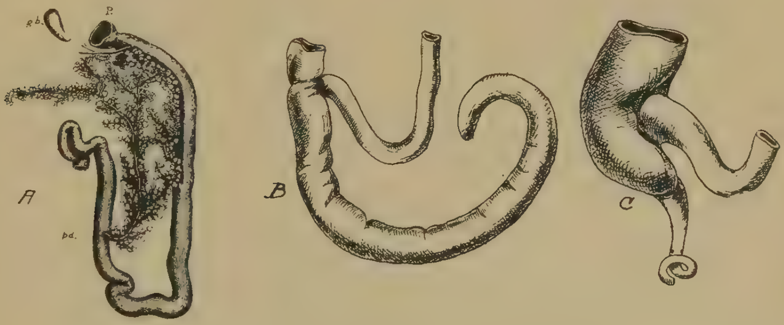

Fig. 436.

A, The duodenum of a rabbit. *P.*, Pyloric end of stomach; *gb.*, gall bladder with bile duct and hepatic ducts; *p.d.*, pancreatic duct. (From Krause after Claude Bernard.)

B, Appendix vermiformis of kangaroo; *C*, Appendix vermiformis of human embryo. (After Wiedersheim.)

Any blind pouch is called a **caecum.** At the beginning of the large intestine where the small intestine enters into it, the joining itself is called the **ileo-caecal junction**, and the little projecting end of the large intestine is the caecum. It is the tapering end of this caecum which forms the **appendix** (Fig. 436) in man and in some of the other vertebrates. There is also a valve at the junction of the ileum and caecum known as the ileo-caecal valve.

The first part of the small intestine which follows the duodenum is known as the **jejunum,** while the more distal portion is the **ileum.**

Professor Wilder gives the following interesting account of the appendix and succeeding structures:

"At the junction of the small intestine with the large, there is a strong tendency to form one or more **caeca,** or blind sacs, which often become digestive organs of great physiological efficiency. The characteristic form in reptiles is that of a single rather short and wide caecum, symmetrically placed. In birds there are usually two symmetrical ones, which attain great length in scratching birds (e. g., the common fowl), and in ducks and geese, but are quite rudimentary in certain others (woodpeckers, parrots, etc.). Ostriches possess a single caecum of great length (seven to eight meters) and furnished with an internal spiral partition, which greatly increases its effective surface.

"In mammals a single caecum is developed, which varies greatly in size and functional importance. Rudimentary in edentates, most insectivores, and bats, it frequently attains an enormous size in herbivorous or graminivorous forms. In certain rodents (e. g., muskrat, woodchuck), its total capacity equals or exceeds that of the remainder of the alimentary canal, and in the marsupial **Phascolarctus** it is three times the length of the body. In the rabbit it is provided with an internal spiral valve; in certain other rodents and in the higher apes and man, the free end becomes rudimentary, restricts its lumen, and forms a worm-like process, the **processus** (appendix) **vermiformis,** which like all rudimentary organs, is subject to a large amount of individual variation.

"Thus in the human subject the appendix varies in length between the limits of 2-23 cm., the average for an adult being 8-9 cm. It is longest proportionally during fetal life, its length relative to that of the large intestine being 1:10, while in adult life it is 1:20. It is longest absolutely between the ages of ten and twenty, after which it shows a slight reduction. Its status as a rudiment of slight functional value is shown by the tendency toward the obliteration of its lumen, a tendency which increases steadily with age. Furthermore, these two characters, reduction in length and obliteration of the lumen, go hand in hand, short appendices being usually solid, while large ones are apt to possess a lumen.

"The position and arrangement of the colon varies considerably among various mammals. In man it begins low down on the right side, from which there proceed in order an **ascending, transverse,** and **descending portion,** connected with the rectum by a **sigmoid flexure,** through which the tube attains the median line; a similar disposal is seen in many other anthropoids, in lemurs and rodents, the majority of carnivores, and a few others. A more complex condition than this is produced by the formation of long, narrow loops along the course of either the ascending or transverse colons, or both, and these loops may remain simple or roll into spirals. Such **colon labyrinths** are seen in ruminants, in certain rodents as the lemmings and jumping mice, and in a few lemurs.

"From this brief review of the alimentary canal and its modifications the impression is gained that in this array of enlargements, elongations, diverticula, spiral valves, and other devices, we have to do, not with a consecutive anatomical history, but with numerous special cases of physiological adaptations, developed in response to need; and that a similarity in one of these particulars implies, not genetic relationship necessarily, but a similar demand responded to in a similar way. The main object to be achieved in all cases is to regulate the amount of digestive surface to the demands offered by the various kinds of food, and as there is but a limited number of mechanical or architectural devices possible, the same ones are employed in unrelated groups of animals, having arisen independently in response to a similar physiological need. This phenomenon of **parallel development** (or 'analogical resemblance,' as Darwin calls it), may appear in any system or part and has been a frequent source of error in the estimation of the inter-relationship of animals."

It has already been shown that the intestinal tract begins as a straight tube, and enlargements take place in various portions of this tube, the most prominent enlargement being the stomach. This enlargement has various paired nerves passing down each side of the digestive canal, prominent among which are the **vagus nerves.** When the stomach has become sufficiently large and extends some distance ventral, it **turns,** so that what was the ventral region now points toward the right side of the individual. This means that any nerves or blood vessels which lie along the right side of the embryonic digestive tract will then lie on the dorsal surface of the stomach and, of course, the left nerves and blood vessels then become ventral. It will save considerable confusion of thought if this be remembered.

THE LIVER (HEPAR)

The **liver,** as well as the **pancreas** (Fig. 293)—the two largest digestive glands—are derived from the mucosa of the intestine. The former grow by a ventral, and the latter by a dorsal, evagination. These organs are in one sense of the word really enlarged intestinal glands which pushed their way through the mucosa, submucosa, and musculosa of the intestine, and then, as they pushed against the serosa (that tissue being held down very loosely), the serosa stretched and grew directly ahead of the two glands. The liver and pancreas are therefore covered by a serous membrane, and both are connected on the side from which they pushed forth by a double layer of serosa which form their respective mesenteries. This serous covering is continuous with the covering of the entire intestinal tract and is known as the visceral **peritoneum** which also forms the lining of the abdominal cavity.

The liver is the largest gland in the body, but no matter how many lobes it may develop or how large it may grow, a layer of serosa covers every part of the gland except that part lying toward the side from which it grew. Here, as stated, the layers coming from each side naturally unite and form the double layer of serosa—the mesentery. The two large **suspensory mesenteries** of the liver are called the **ligamentum hepato-gastricum** (sometimes also called the **lesser omentum)** and the **ligamentum suspensorium-hepatis.**

Practically the entire length of the digestive canal which passes through the body-cavity is attached by both a dorsal and ventral mesentery. The ventral mesentery becomes lost below the region of the liver, leaving a sharp ventral edge to the two hepatic ligaments.

The function of the liver is to secrete **bile (gall),** as well as to form various internal products such as **glycogen, urea,** and **uric acid,** all of which substances are of great importance to the living animal. The bile is sent to the intestines through the **bile duct** (also called **choledochal duct),** while the other products are carried away by the blood. Substances which are not sent through a duct but are carried throughout the body by the blood stream are known as substances of **internal secretion.**

The liver is a **compound tubular gland.** The many little tubules in the liver which form the gall capillaries empty into the bile duct. This tubular condition of the liver is easily seen in **ichthyopsida,** but is difficult to observe in mammals because of the tubular anastomosis and because of the close interrelation of the bile vessels and blood vessels.

The liver begins its growth cephalad, at about the same time the blood vessels have already developed into the large **sinus venosus** and **hepatic veins.** These blood vessels also contribute to the **septum transversum** (Fig. 348). The growth of these latter organs prevents the liver from continuing the cephalad growth so that from now on it increases in size in an opposite direction.

Concomitant with its increase in size there is an immigration of mesenchyme between the lobules of the liver. The blood vessels enter at this time. The bile duct (if there are several, this is only true of one of them) has a lateral diverticulum or enlargement. This is the **gall bladder** (Figs. 426, II, 436), which serves as a reservoir for the bile. It may be found in the substance of the liver itself, but is usually more or less separate and lies dorsal to the liver substance. It is lacking in some mammals. In fact, it is not uncommon in man to have it removed surgically.

Both the liver and the gall bladder have ducts leading from them.

Those coming from the liver are called **hepatic ducts**; those from the gall bladder are called **cystic ducts** (Fig. 436). These unite, forming the **common duct** which is also called the **choledochal duct.** It is this common or choledochal duct which empties into the intestine. The liver has many and varying shapes in the different animals, depending to a large extent not only upon the shape of the body but on the shape and size of the organs which press upon it. The color of the gall may vary from a brown, yellow, purple or green, to a vermilion.

THE PANCREAS

This is the second largest of the digestive glands (Fig. 436) and secretes digestive ferments of great strength, such as **trypsin, steapsin, and amylopsin,** which digest both proteins and carbohydrates.

In some respects the pancreas resembles the salivary glands and so compensates in part for the absence of such glands in the lower vertebrates. This pancreas arises, as already mentioned, from the dorsal wall of the intestine, close to the liver. There are usually **three diverticula,** one dorsal and two ventral. These latter soon unite. In sharks there is only a single diverticulum, while in the sturgeon there are not only two dorsal but also an equal number of ventral. The proximal portion forms the ducts, the distal, the glands. The number of ducts that persists varies immensely. In some forms of animals all but one disappears, while in the lampreys all may be lost. However, in the mammals there are usually two ducts persisting, the ventral known as the **pancreatic or Wirsung's duct,** and the dorsal called the **accessory** or **Santorini's duct.** Again, the ducts may all remain distinct, or they may unite before they enter the intestines. One of them may even unite with the bile duct. While not absolutely proved, it seems that all vertebrates have some form of pancreas. This may be only a slender tube in the mesentery, as in teleosts, or it may lie outside the muscles in the intestinal walls as in **dipnoi.** In the **cyclostomes** it is partly concealed at the insertion of the spiral valve, partly in the liver. In these forms, however, the duct has entirely disappeared so that it forms one of the **ductless glands,** or in other words a **gland of internal secretion.** The pancreas varies in shape and size. It may be long and straight or possess many lobules. Almost always it is placed between the duodenum and the stomach. There is a question as to whether or not the gland is composed of two separate and distinct structures.

SUMMARY OF THE DIGESTIVE SYSTEM

AMPHIOXUS

The mouth lies at the bottom of a vestibule (Fig. 437) and is an **oral funnel** bounded by ciliated **buccal tentacles,** with cartilaginous supports that serve to funnel the water into the pharynx. The mouth is surrounded by a membrane, the **velum,** which acts as a sphincter muscle. A set of **velar tentacles** that serve as a grating to strain out the larger particles is developed on the free edges of the velum.

The **pharynx** has sometimes upward of fifty or more pairs of **gill-clefts** (also called **branchial apertures**) that are separated by partitions in which lie cartilaginous **skeletal rods,** connected across with one another, forming a sort of **branchial basket.** These apertures serve as means of communication between the pharynx and the atrium (the space between the pharynx and the body-wall). The **endostyle** (a longitudinal groove on the ventral side of the pharynx), the **peripharyngeal** and **hyperpharyngeal grooves,** all secrete mucus in the form of a continuous rope which carries the food along with it to the stomach. The **atrium** is a sort of mantle, composed of folds of the body-wall that enclose the whole branchial apparatus in a voluminous water-filled chamber, the **atrial cavity.** The atrium is lined with ectoderm and has but one opening to the exterior, a posteriorly directed **atriopore,** which carries off the water that comes through the pharyngeal clefts. The atrium is a protection for the delicate pharynx while the animal is in its sandy burrow and helps to maintain an uninterrupted current of water.

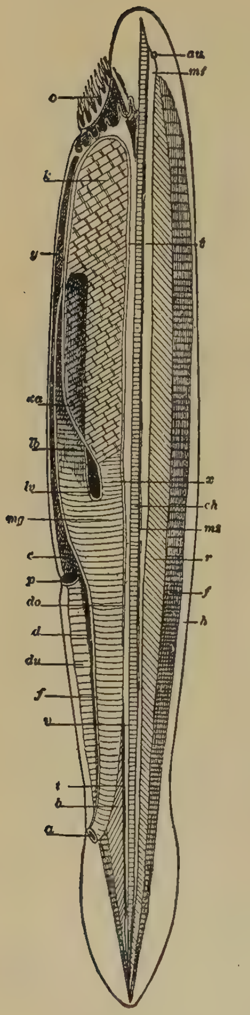

Fig. 437.

Amphiox'us lanceola'tus: *a*, Anus; *au*, eye; *b*, ventral muscles; *c*, body cavity; *ch*, notochord; *d*, intestine; *do* and *du*, dorsal and ventral walls of intestine; *f*, fin-seam; *h*, skin; *k*, gills; *ka*, gill-artery; *lb*, liver; *lv*, liver-vein; m^1, brain vesicle; m^2, spinal marrow; *mg*, stomach; *o*, mouth; *p*, ventral pore; *r*, dorsal muscle; *s*, tail fin; *t*, *t*, aorta; *v*, intestinal vein; *x*, boundary between gill intestine and stomach intestine; *y*, hypobranchial groove. (After Häckel.)

ASCIDIANS (TUNICATES)

In the Ascidians (Fig. 313, IV) the method of food concentration and transportation is similar to that of **Amphioxus,** although the apparatus which carries on this function seems to be of an improved type more appropriate for a sedentary life. An **atrial cavity** surrounds the pharynx which in turn is enclosed by a mantle that surrounds the whole body. A thick **tunic** (after which the animal takes its name) covers this mantle. The **atriopore** is not posterior in direction, but lies close to the mouth and is forwardly directed. The stomach opens near the bottom of the pharynx, and the intestine takes a complete turn and opens forward into the atrium. There is no notochord and no neural tube. Practically none of the structures characteristic of the dorsal side of **Amphioxus** are present.

FISHES

The mouth opens directly into the capacious pharynx, which is perforated by five gill-clefts and the paired spiracles. A short oesophagus of large caliber leads into a U-shaped stomach (Fig. 438), which in turn

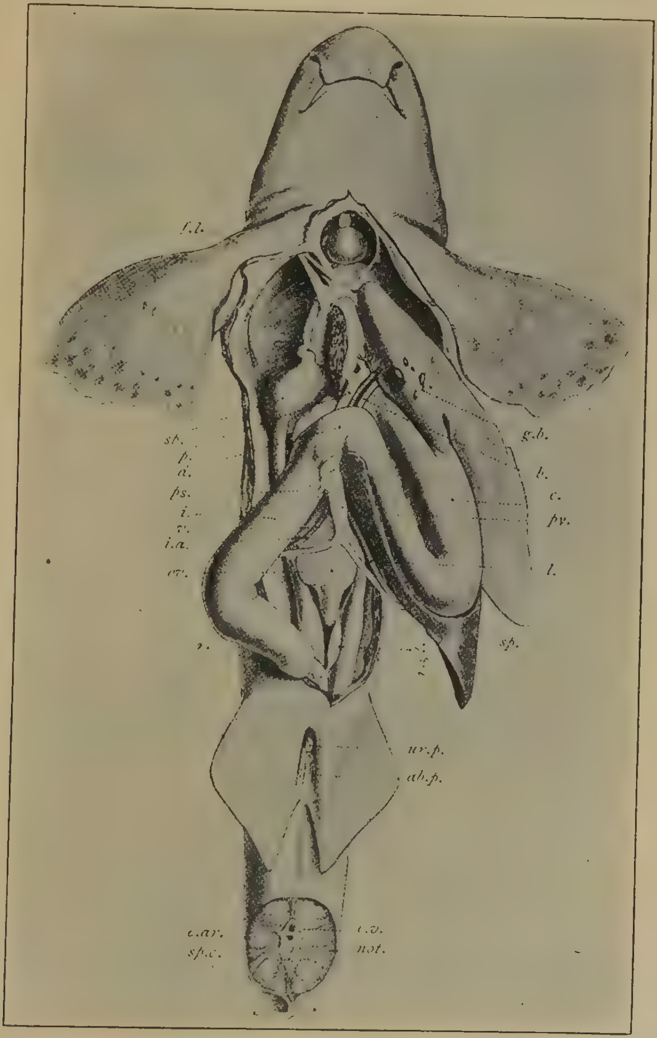

Fig. 438.

A female dogfish in which the abdominal and pericardial cavities have been opened from the ventral side, and the viscera somewhat displaced. The pericardium has been opened slightly to the left of the middle line, and the right lobe of the liver has been cut away.

ab.p., Abdominal pores; *b.*, bile duct; *c.*, cardiac limb of stomach; *c.ar.*, caudal communicates with the intestine through a valve-shaped opening controlled by a sphincter muscle. The cardiac end of the stomach may end as a blind pouch. The organ is often sufficiently distensile to permit one animal to swallow another as large as itself. The intestine is short but of large diameter and has a secreting surface greatly enlarged by a fold in the shape of a spiral staircase (present, however, in very few **teleostei)** called the **spiral valve.** All primitive fish have this spiral valve. A large bi-lobed liver, which is provided with a gall bladder and a bile duct, opens into the intestine. The pancreas also pours its secretion into the intestine.

TURTLES

The digestive system of reptiles varies somewhat in carnivorous and herbivorous forms, but in all turtles it is comparatively simple In the turtle there are no teeth. The tongue is broad and soft and cannot be protruded. The stomach is a simple U-shaped enlargement of the alimentary tract. The intestine is without a caecum; it is clearly divided into large and small intestines. The cloaca is proportionately large.

AVES

The mouth is hard and narrow and the tongue is hard and often of great functional value. The oesophagus which has many large cornified papillae, develops an enlargement called the crop. The stomach has a **proventriculus** which secretes the gastric juice, and a **muscular gizzard** or **gastric mill.** The intestine is U-shaped, and is composed of duodenum, ileum, and rectum. Between the ileum and rectum there are two **caeca.** The rectum opens into a cloaca. There are two bile ducts but no gall bladder. The pancreas empties into the duodenum. The intestine is found to be longer and more coiled in ascending vertebrates. In **cyclostomes, teleostomes,** and **all non-placental mammals, the intestine terminates in a cloaca,** as do also the urinary and genital ducts. In placental mammals and in cyclostomes and teleostomes the urinary and genital ducts have a distinct and separate opening from that of the intestine.

MAMMALS

In all vertebrates (except birds and mammals) the coelom consists of the following two compartments:

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artery; *c v.*, caudal vein; *d*, bursa Entiana; *f.l.*, falciform ligament appearing on surface of left lobe of liver in which it is embedded; *i.*, intestine; *i.a.*, intestinal branch of anterior mesenteric artery; *l.*, lienogastric artery; *not.*, notochord; *ov.*, ovary; *p.*, portal vein lying beside hepatic artery; *ps.*, pancreas with duct opening into intestine; *py.*, pyloric limb of stomach; *r.*, rectum, between hinder ends of oviducts, with rectal gland (*r.gl.*) attached to its dorsal side; *sh.*, right shell gland on course of right oviduct; *sp.*, spleen; *sp.c.*, spinal cord; *ur.p.*, urinary papilla; *v.*, branch of portal vein formed by junction of intestinal and splenic veins.

Besides the above, note—nostrils; oronasal grooves; mouth; pectoral and pelvic fins; pericardial and abdominal cavities; heart, consisting of sinus venosus (behind), ventricle, auricle (showing at sides of ventricle), and conus; cloaca, and transverse section of tail, showing at the sides the myomeres, above the anterior dorsal fin, and in the middle the cartilage of the backbone enclosing spinal cord, notochord, and blood vessels. (After Borradaile.)

(1) The **pericardial cavity** which contains the heart only.

(2) The **pleuroperitoneal cavity** which contains the other viscera.

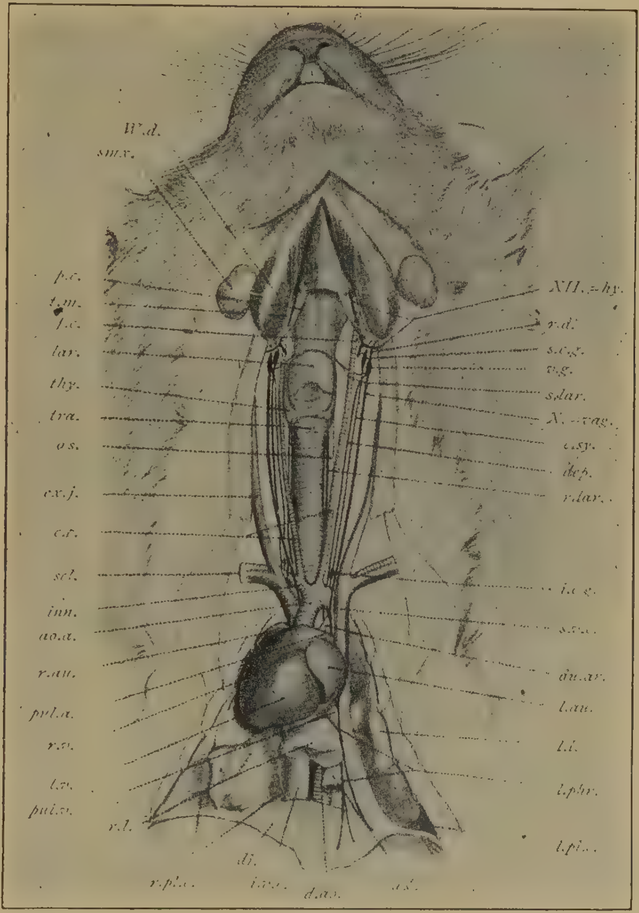

Fig. 439.

A dissection of the neck and thorax of a rabbit. The heart has been displaced a little to the right, and the pericardium removed.

ao.a., Aortic arch; *c.c.*, common carotid arteries; *c.sy.*, cervical sympathetic nerve; *d.ao.*, dorsal aorta; *dep.*, depressor nerve; *di.*, diaphragm; *du.ar.*, ductus arteriosus; *ex.j.*, external jugular vein; *f.c.*, point at which the common carotid divides; *hy.*, hypoglossal nerve; *i.c.g.*, inferior or posterior cervical sympathetic ganglion; *inn.*, innominate artery; *i.v.c.*, inferior vena cava, lying in mediastinum; *l.au.*, left auricle; *l.l.*, left lung; *l.phr.*, left phrenic nerve; *l.pl c.*, left pleural cavity; *l.v.*, left ventricle; *lar.*, larynx; *œs.*, œsophagus in neck; *œs'.*, the same in mediastinum; *p.c.*, posterior cornu of the hyoid; *pul.a.*, pulmonary artery; *pul.v.*, pulmonary vein; *r.au.*, right auricle; *r.d.*, ramus descendeus; *r.l.*, right lung, one part bulging into mediastinum; *r.lar.*, recurrent laryngeal nerve; *r.pl.c.*, right pleural cavity; *r.v.*, right ventricle; *s.c.g.*, superior cervical sympathetic ganglion; *s.lar.*, superior laryngeal branch of vagus; *s.v.c.*, superior vena cava; *scl.*, subclavian artery and vein; *smx.*, submaxillary gland; *t.m.*, tendon of mandibular muscle; *thy.*, thyroid gland; *tra.*, trachea; *v.g.*, vagus ganglion; *vag.*, vagus; *W.d.*, duct of submaxillary gland (Wharton's duct); *X.*, *XII.*, cranial nerves. (From Borradaile.)

A partition, the **transverse septum** (Fig. 348), separates the two cavities. In vertebrates lower than **Anura** the pericardial cavity lies cephalad to the pleuroperitoneal cavity, but beginning with the **Anura**, the pericardial cavity comes to lie ventral to even the cephalic end of the pleuroperitoneal cavity, because the heart and the pericardial cavity descend and carry the transverse septum with them. This descent causes the wall of the pericardial cavity, together with the transverse septum, to form a sac—the pericardial sac—around the heart.

The part of the pleurocardial cavity dorsal to the heart later becomes the pleural cavities.

In birds and mammals the pleuroperitoneal cavity divides into anterior and posterior regions by a partition which descends from the dorsal body-wall to unite with the transverse septum. This partition is known as the **oblique septum** in birds and the **diaphragm** in mammals (Fig. 439). In mammals this diaphragm contains a great amount of striated muscle.

In birds and mammals the coelom has become divided into four compartments: one **pericardial,** two **pleural** and **one peritoneal cavity.**

While a dorsal mesentery supports the digestive tract in all vertebrates, the ventral mesentery is absent in the adult, except in the regions of the liver and bladder.

In mammals, the mesentery of the stomach is prolonged posteriorly to become the greater omentum. An ileo-colic valve and a single caecum are usually found where small and large intestine meet in mammals, although there are a few instances where there are two caeca. In some **edentates,** in bats, in some carnivorous animals, and in many whales, neither valve nor caecum are found.

In some rodents and marsupials the caecum grows as long or longer than the animal's body (it is of great value in digestion here), while in man, it degenerates into the vermiform appendix, the lumen of which tends to close with increasing age.

In mammals the intestine and colon are straight tubes at first but grow into folds later.

In monotremes the rectum terminates in a cloaca as it does in the **Sauropsida.** This condition also occurs in the young of all mammals, but, in all these, the urogenital and digestive openings become separated later, and a **perineal fold** develops between the openings.

CHAPTER LII.

THE RESPIRATORY SYSTEM

It will be remembered that in studying the frog, the trachea and oesophagus have their beginning close together at the caudal end of the pharynx which is also the beginning of the cephalic end of the larynx. In the higher forms of animals the trachea divides into two **bronchii.** These bronchii again continually subdivide until there are many tiny tubules called bronchioles spreading out to all parts of the lungs. These bronchioles form a sort of an air-capillary system through which the inspired air is sent to all parts of the lungs, there to assist in aerating the entire pulmonary blood which has been sent to the lungs from the heart, through the pulmonary artery. In order that the oxygen in the inspired air can come in direct contact with the blood itself, there must be a rather thin, more or less porous, membrane separating the blood and air.

The lungs, liver, spleen, and kidneys are known as **parenchymatous organs.** It is well to bear this in mind constantly, for many diseases find their way from one of these organs to another. A parenchymatous organ is more or less sponge-like and consists of loosely woven tissue in which there are many porous openings. Such organs are invariably supplied with great quantities of blood.

These organs, especially the lungs, have a decidedly thin membrane surrounding the sac-like ends of the bronchioles. Here the oxygen passes through the thin walls to come into direct contact with the venous blood which has been sent there through the pulmonary artery.

What has been said so far regarding the respiratory system applies to vertebrates at large, although those who live a part of their lives in water, have no lungs during that period, and in this respect resemble fish and other animals which spend all of their time in the water. In such forms gills (also called **branchiae)** develop on the walls of some of the **visceral clefts** (these are also called **gill clefts** (Fig. 295) or **branchial clefts).** The clefts come from the sides of the pharynx and begin as a pair of pouches or grooves of the pharyngeal entoderm. Extending toward the sides of the animal they push aside the mesoderm until they reach the ectoderm. The ectoderm and entoderm then fuse to form a plate. This plate becomes perforated, thus connecting the pharynx with the exterior of the body by a number of openings. These openings or clefts begin development at the cephalic end and successively continue caudad.

The visceral pouches, although developing in all verteberates, do not as a rule break through in the mammals. In fact, the pouches may disappear without leaving any trace whatever except a **Eustachian tube** and the various ductless glands already mentioned. In the true vertebrates fourteen pairs of these clefts is the largest number found although there are more than this in **Amphioxus** and **Balanoglossus.** In the cyclostomes there are usually seven (eight to seven in notidanid sharks, five or six in teleostomes, and five in birds and mammals). In this numbering the oral cleft is not included though there is some evidence that the mouth arose by the coalescence of a pair of gill clefts.

The gill clefts do not form a serial repetition in the same manner as does segmentation in other parts of the body, and it may even be that the metamerism of the head is not of the same character as the metamerism of the gill clefts. In the amniotes where gills are never developed the branchial pouches or clefts, however, appear and bear practically the same relation to the aortic and branchial arches as in the lower forms. From this, it is often assumed that all of these higher forms having this relation have had ancestors with gills.

There is an **interbranchial septum** covered externally with ectoderm and internally with entoderm between every two successive gill clefts. The inner portion of this septum is composed of mesoderm which in its earlier stages contains a diverticulum of the coelom. Later, blood-vessels (aortic arches) and skeletal elements (visceral arches) are developed in each septum, the visceral arches forming on the splanchnic side of the coelom and hence are not comparable to girdles or ribs.

In **Cyclostomes** and fishes the gills are either filamentous or lamellar outgrowths of epithelium, which have developed on both anterior and posterior walls of the interbranchial septa. Each gill contains a loop of blood-vessel. There are two very thin layers between the blood and the surrounding water, which thus permit an exchange of gases.

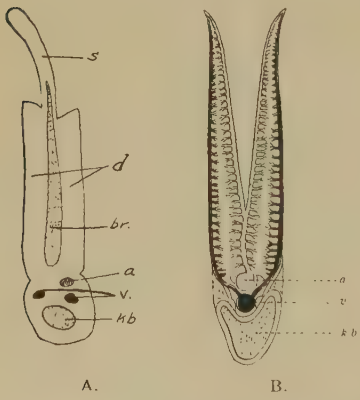

Fig. 440.

Diagram of a gill. *a*, gill-arteries; *br*, branchial ray; *d*, demibranchs; *kb*, cross section of bone of branchial arch; *s*, septum; *v*, veins. (*B*, after Cuvier.)

The filaments (sometimes called gill-plates), (Fig. 440), which bound each gill anteriorly and posteriorly on one side, form a demibranch, and it is the two demibranchs of a septum which then constitute a gill. This means that each cleft is bounded by demibranchs belonging to two gills.

Some forms have external gill-filaments in the very young which are later absorbed.

In sharks that have more than five gill clefts, as well as in the **Cyclostomes,** the first cleft bears gills, but in many elasmobranchs, as well as in the ganoids (sturgeon and

Polypterus), this cleft becomes smaller and smaller until there is only a dorsal opening on the head—the **spiracle.** In most vertebrates this spiracle is closed in the adult but in the tailless amphibia and the higher mammals the inner portion persists as the Eustachian tube and the greater part of the middle ear.

There are two types of gills in fishes. Practically all the elasmobranchs with the exception of the **chimaeroids**, have the interbranchial septum well developed so that it extends beyond the demibranchs and thus differentiates an excurrent canal in the cleft. The prolonged septum bends caudally at the outer end to protect the gills from injury.

In teleostomes and chimaeroids the broad fold of the posterior end of the hyoid arch grows backwards over the clefts to form a gill-cover or opercular apparatus. The gill-cover encloses an extrabranchial or atrial chamber into which the clefts empty. The chamber opens by a single slit behind the operculum.

In those instances, just mentioned, when an operculum is developed the interbranchial septum is always reduced in size until there is only a slender bar from which the demibranchs extend into the atrial chamber. The two opercular folds are usually continuous beneath the pharynx.

In teleosts and ganoids the operculum (gill-cover proper) is usually differentiated from a more ventral portion known as the **branchiostegal membrane** which is quite flexible, and possesses a skeleton of slender **branchiostegal rays.** The ventral wall of the pharynx in these cases is nothing but a slender bar and is called the **isthmus.**

Just as the air in the lungs in the higher forms of animals is taken in through the outer air passages and then passes through the trachea, bronchia, and bronchioles to the delicate septa in the lungs, so in animals possessing gills there is likewise a delicate septum which separates the blood from the stream of water which is constantly being passed over the gills. Water is as a rule drawn into the mouth and as the enlarged oral cavity contracts it is forced out through the clefts, passing over the gills on its way. In the **Myxinoids** the oesophageo-cutaneous duct probably acts as the incurrent passage when the animal has the front of the head immersed in the flesh of a fish. In the lampreys the water is probably taken and forced out through the gill clefts when the animal is attached to some object. The spiracle serves as an incurrent opening in many elasmobranchs, and it is provided with a valve which develops from the anterior wall and closes to prevent any backflow. Sturgeons and **Polypterus** have spiracles throughout life.

Sharks have the gill clefts on the side in the so-called neck region while skates have them on the lower surface of the body. This difference is brought about by the union of the anterior appendages with the head in skates.

Many teleosts have breathing valves at the mouth opening which permit water to enter but not flow out again. In such cases there is a more posterior pair formed by the branchiostegal membrane closing the opercular opening through which the outflow of water may occur.

In some of the teleosts and in such forms as **Polypterus** there is an opercular gill with respiratory functions developed on the inner surface of the operculum, while in some of the elasmobranchs (even those in which the spiracle is closed), **pseudobranchs** composed of vertical folds are developed on the anterior wall of the cleft. These are homologous with gills but they are not respiratory, as they receive only arterial blood which passes from the pseudobranch to the choroid coat of the eye and sometimes even to the brain.

AMPHIBIA

In the amphibia, although the gill pouches form just as they do in fishes, the first and fifth never break through, while in nearly all adult forms all the clefts are closed. Exceptions occur in **perennibranchs** and the **derotremes** in which from one to three external openings persist.

In the tailed amphibia and in the caecilians the operculum is merely a fold of integument in front of the gill-area (Fig. 341). The operculum develops without a skeleton support in the larva of tailless amphibians. This fold grows backward over the gills and fuses. Thus there are atrial chambers formed which usually open by a single excurrent pore to the exterior. In a few forms, however, both right and left excurrent openings occur.

It is usually conceded that the gills of amphibia are of ectodermal origin, and that there may be both external and internal gills present at the same time. In the tailless amphibia, such as frogs, the operculum grows over the gill clefts, and the external gills are folded into the atrial chamber where they are gradually reduced, while the gills which developed from the walls of the clefts become functional. At the time of metamorphosis the clefts are entirely closed and the gills absorbed.

It has usually been taught that the gills of fishes were entodermal in origin, but if this is true, they cannot be homologues of the amphibian gills. However, the structures are so much alike in appearance, in structure and in function, that it seems they must be homologous. Nevertheless, more evidence will have to be awaited before positive assertions of value can be made.

It may be interesting, and it may with further knowledge some time prove of value, to note from the foregoing, that amniotes have visceral pouches in the embryo, though gills are never developed in the adult; that reptiles have five of these pouches—birds and mammals four. In man only the first breaks through to form a cleft, while in many of the higher forms there are grooves on the outside of the neck which show their original position. The manner of obliterating these external grooves is as follows: The arches most cephalad, especially the hyoid, after enlarging, slides back over those lying more caudad so that at least the external branchial grooves lie in a pocket called the **cervical sinus.** This sinus is later closed by a process from the hyoid arch extending over it quite similarly to the development as shown in **Anura.** Internally the entodermal branchial pouches, with the exception of the first, disappear, but the first persists as the Eustachian tube and the greater part of the middle ear.

THE SWIM BLADDER

The swim bladder arises as a diverticulum of the alimentary canal remaining in contact with that canal by a pneumatic duct in the ganoids and one group of teleosts **(Physostomi),** (Fig. 441). This duct, although usually emptying into the oesophagus, may connect with the stomach. However, in most teleosts the duct disappears entirely at an early date. The swim bladder lies dorsal to the digestive duct outside of the peritoneum, although below the vertebrae and excretory organs. It may be of almost any dimensions, sometimes extending the entire length of the body. In some forms of teleosts, which remain almost constantly at the bottom, it is absent entirely. The swim bladder, although usually unpaired, is paired in most ganoids and may even form three divisions of connecting sacs. There may be diverticula of any and all kinds. The internal part of it may be smooth and simple or it may be subdivided by various septa, or it may even be alveolar resembling the lungs of higher vertebrates. There may be striated muscle fibers in the walls, and in some **Siluroids** and **Cyprinoids** they are even somewhat calcified on account of some of the vertebral processes being **included.**

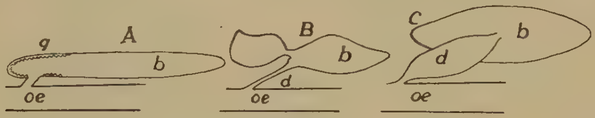

Fig. 441.

Swim-bladders of those fresh-water fish whose air-bladders have a duct (physostomous). *A*, Pickerel; *B*, Carp; *C*, Eel. *b*, swim-bladder; *d*, duct; *g*, red gland; *oe*, oesophagus. (From Kingsley after Tracy.)

The blood supply of the swim bladder is arterial, and comes from either the aorta or the coeliac axis; sometimes different portions receive blood from both these vessels. The arteries break up in the walls to become networks of minute vessels known as **retia mirabilia.** These often form **"red spots"** on the inner surface. From the retia the blood passes to the postcardinal, hepatic or vertebral body-veins, in the ganoids and phystomous species, especially those with a wide pneumatic duct.

The swim bladder contains a greater quantity of O_2 than is found in solution in the water in which the fish lives. It is therefore probably a storage organ for O_2 for use when the fish dives to lake bottoms in the summer for food. This can be understood the better when it is remembered that there is no O_2 at all at the bottoms of lakes in summer.

The swim bladder is supposed to make it possible for its possessor to regulate its equilibrium while in its watery medium. This supposition has the following facts upon which to rest its validity: ground-feeding teleosts do not have it, but those who must adjust their position in such a way as to obtain the requisite food do have it, while in many of these there is a diverticulum from it to various portions of the ear.

LUNGS AND AIR DUCTS

In all the higher forms of animals and in some few fishes—dipnoids—the lungs arise as an outpushing from the ventral side of the pharynx immediately behind the last gill pouch. This outpushing divides almost immediately into a right and left half, and just as the outgrowing from the digestive tract carried the covering of that tract before it, so, too, a peritoneal covering is carried before the respiratory organs.

As development goes on, the growing part protrudes into the coelom so that the parts lying therein have an entodermal lining which was derived from the epithelium of the pharynx, while the outer layer of peritoneum is serous mesenchyme carrying blood and lymph vessels, nerve and smooth-muscle fibers between the two. That portion of the respiratory system from the pharynx to the lungs consists of trachea, bronchi, and their accessories. These together constitute what are commonly called **air ducts.** The lungs are treated as distinct from these.

On the ventral side of the trachea, in air-breathing animals, there is a separation which forms the **larynx** (Fig. 442), the beginning of which can be studied in amphibia, in the lower forms of which, a simple pair of cartilages are developed on the sides of the **glottis** (the glottis simply being an elongated slit connecting the pharynx with the air ducts). These cartilages develop in the position of a reduced visceral arch. In other forms, such as the **Urodeles,** the more cephalic ends of the lateral cartilages separate from the rest and form an **arytenoid** which is the first of the laryngeal cartilages, and is imbedded in the walls of the glottis. The balance of the lateral cartilages may remain as it is, or divide into any number of pieces. However, the more cephalic pair of these pieces often fuse in the mid ventral line to form the **cricoid,** which is the second element of the laryngeal framework. There are various **antagonistic muscles** attached to these cartilages which make it possible to open and close the opening.

The **vocal cords** are formed by a pair of folds of the laryngeal lining which extend parallel to the margins of the glottis. Sound is produced by the vibrations caused by the air passing over these cords as they are relaxed or tightened in different degrees. The larynx is quite rudimentary in reptiles and birds. In the latter the **syrinx,** shortly to be described, takes the place of the larynx.

In the mammals one or more **thyroid cartilages** are added on the dorsal side to those already described. In the monotremes the hyoid apparatus and the larynx are most intimately connected, but in the higher forms of mammals such an association is not so intimate even in the embryo.

The thyroid cartilage forms a half ring on the ventral side of the anterior end of the larynx in the higher mammals. The anterior dorsal angles form cornua which connect with the hyoid by a ligament. Dorsal to the thyroid is the **glottis** with the **arytenoids** in its walls. Posterior to the glottis is the ring-shaped **cricoid,** which is followed by the **trachea.** Anterior to the glottis lies the epiglottis, which is a fold of mucous membrane supported by an internal cartilage which articulates with the anterior margin of the thyroid. The epiglottis usually stands erect, thus leaving the glottis open during respiration, while during deglutition it is pulled back into the glottis, supposedly preventing the entrance of food into the trachea, but there are numerous cases on record where the epiglottis has been removed and such individuals seem to have no difficulty with their food getting into the "wrong throat."

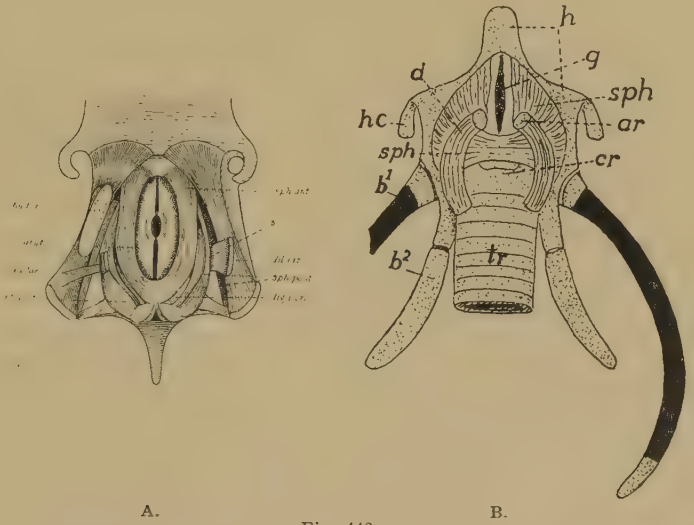

Fig. 442.

A, Muscles of larynx (voice box) of *Rana esculenta.* Dorsal view. *aryt.,* arytenoid cartilage; *dil.lar.,* dilator muscle; *hy.lar.,* hyo-laryngeus muscle; *lig.i.cric.,* intercricoideum ligament; *s.,* tendon of posterior sphincter muscle; *sph.ant.,* anterior sphincter muscle; *sph.post.,* posterior sphincter muscle. (After Gaupp.)

B, Laryngeal apparatus of a Turtle. *ar,* arytenoid; b^{1-2}, first and second branchial arches; *cr,* cricoid; *d,* dilator laryngis muscle; *g,* glottis; *h,* hyoid; *hc,* hyoid cornua; *sph,* sphincter laryngis; *tr,* trachea. Cartilage is dotted, bone is black. (From Kingsley after Göppert.)

The cavity of the larynx bears a **vocal cord** on either side internally. These are folds of the mucous membrane which extend from the thyroid to the arytenoids, and by moving these latter cartilages they can be tightened or relaxed to alter the pitch of the note caused by their vibration. A pocket lies anterior to the cords, the **laryngeal ventricle (sinus of Morgagni)**, one on each side, quite small in most mammals, but well developed in the anthropoid apes to large vocal sacs. In the chimpanzee there is a median vocal sac in addition. These act as resonators and add strength to the voice.

The larynx is prolonged in whales and marsupials so that it projects into the choana behind the soft palate. This is an adaptation to the manner of taking food from the water and breathing at the same time in the whales, while in the young marsupials the milk is forced into the mouth by the muscles of the mammae of the mother, an arrangement that prevents strangulation.

The trachea (Fig. 442) in the higher forms has a **series of cartilaginous rings** forming its walls. It varies in length and size as well as the quantity of cartilage strengthening its walls in the different genera. It is as a rule shortest in lizards and often convoluted in turtles. The cartilaginous rings may be entirely complete or the dorsal part of the ring may be of membrane. It is usually longest in birds.

It is interesting to note that the larynx never forms the voice organs of birds. In this form of animal life, the sound producing parts are formed from membranes which also vibrate by the passage of air, but this voice organ is located at the point where the trachea divides into bronchi and is known as a **syrinx** (Fig. 443). The most common form of this organ is that in which the last rings of the trachea unite to form a **resonating chamber**, the **tympanum**, while folds of membrane, called internal and external tympanic membranes (not to be confused with the similarly named structure in the ear), extend into the cavity from the median and lateral wall of each bronchus.

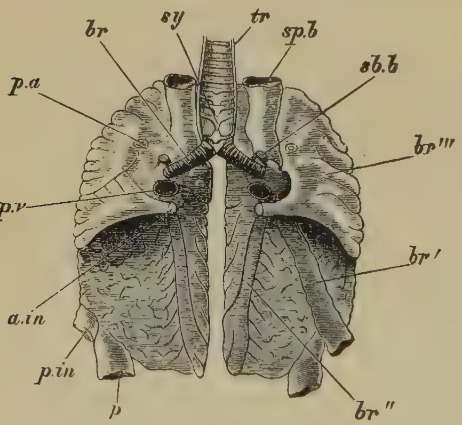

Fig. 443.

Columba livia. The lungs with the posterior end of the trachea, ventral aspect. *a.in.*, aperture of anterior thoracic air-sac; *br.*, principal bronchus; *br'.br.''br'''.*, secondary bronchi; *p.* aperture of abdominal air-sac; *p.a.*, pulmonary artery entering lung; *p.in.*, aperture of posterior thoracic air-sac; *p.v.*, pulmonary vein leaving lung; *sb.b.*, aperture of interclavicular air-sac; *sp.b.*, aperture of cervical air-sac; *sy.*, syrinx; *tr.*, trachea. (From Parker's *Zootomy.*)

In some instances there is also an internal skeletal element called a **pessulus**, bearing a semilunar membrane on its lower surface. This type of syrinx may be a symmetrical and even may form a bony resonating vesicle. There are various muscles attached to trachea and bronchi which permit an alteration of the tension of the folds in all forms of syrinx, thus making it possible to change the sounds uttered.

In the mammals the cartilaginous rings of the trachea are dorsally incomplete, this position being closed by membrane. A structure of this kind permits the tube to remain open and yet also permits it to "give" a little when food passes down behind it through the oesophagus.

THE LUNGS

In the lung fishes there is usually a single sac, although several types of these animals have **paired lungs.** The pulmonary arteries spring from the **last efferent branchial artery** of both sides. The blood supply, therefore, under normal conditions, is arterial, and the lungs cannot act as respiratory organs. "In times of drought **(Protopterus)**, or of foul water **(Ceratodus)**, the gills no longer function, and the pulmonary arteries bring venous blood to the lungs."

In amphibia the two lungs are elongated. They are united at their bases though true bronchi are absent. They may or may not have alveoli. In the frog the two lungs are distinct, the walls being divided into a series of sacs or infundibula lined with alveoli. The infundibula open into a central chamber, which, since it is ciliated and has numerous glands in its walls, may be compared to a bronchiole.

In those terrestrial urodeles which are lungless in all stages of development, no traces of larynx or trachea occur at all, even after the gills are absorbed. In such species there is a considerable development of capillaries in the skin as well as in the walls of the mouth and pharynx, so that the respiratory functions are transferred to these parts. In the frogs, as already shown, the skin is respiratory and largely supplied by the cutaneous arteries arising from the same arch as the pulmonary arteries.

The air ducts enter the anterior end of the lungs in amphibia, while in higher forms the lungs extend anteriorly to the entrance of the bronchi on the medial side. This change is in part the result of the transfer of the heart into the thorax, the position of the pulmonary arteries, thus forcing the bronchi toward the center of the lungs. In amniotes, also, the ducts are characterized by the presence of cartilage in their walls, so that they are true bronchi. The bronchi may extend inside of the lungs and divide into secondary and tertiary bronchi.

In reptiles the lungs are often non-symmetrical, sometimes one even being absent. In the snakes the lungs consist of a single sac lined with infundibula either in part or throughout. In the lizards there are one or more verticle septa dividing the lung into chambers lined with alveoli while a part of the bronchus may extend to the extremity of the lungs. In the chameleons the septa do not reach the distal wall, consequently the chambers communicate so that the bronchus enters a cavity known as the **atrium.** This connects with the various chambers separated by the septa and these in turn open into a terminal vesicle. This whole structure seeming to anticipate the **parabronchi**—the small uniform sized air-tubes in the lungs of birds which connect the larger secondary branches of the bronchial tubes. "This resemblance is heightened by the development in these same lizards of long, thin-walled sacs from the posterior part of the lungs which extend among the viscera, even into the pelvic region." The air sacs are used to inflate the body. It is well to remember what has just been said in the study of similarly named structures in the bird. In turtles and crocodiles there is no atrium and the whole lung has a spongy texture. The bronchus in turtles enters on the ventral side of the lung and not as in lizards in the medial.

SUMMARY OF THE RESPIRATORY SYSTEM

BALANOGLOSSUS

The pharyngeal clefts take the form of gill sacs, each of which opens into the pharynx in a U-shaped slit, resembling that of **Amphioxus**, and opens to the exterior by a small pore. These gill-slit openings to the pharynx are supported by thin, chitinous bars resembling the gill bar system of **Amphioxus.**

FISHES

The characteristic respiratory organs of aquatic vertebrates are **gills** or **branchiae.** Gills are finely divided comb-like outgrowths of the ectodermal or endodermal epithelium lining the branchial clefts. The number of clefts or gill slits vary from five to seven in number. Each cleft is separated from its neighbor by branchial septa. The more primitive the fish, the larger number of branchial clefts it is likely to have. The modern types have regularly five. **Heptanchus,** sometimes mentioned as the most primitive living species of shark, has seven clefts, while **Hexanchus,** another primitive shark, has six, and elasmobranchs in general have five fully developed clefts and a vestigial anterior first cleft called a **spiracle.**

The spiracle is the rudimentary first cleft, which is also found among the most primitive teleostomi (**Crossopterygii** and **Chondrostei**). It is present in the embryos of **Teleostei** and **Holostei,** although here it is closed before hatching. In the **Holocephali,** an aberrant group of elasmobranch fishes, the fifth cleft is closed in the adult, which reduces the number of functional clefts to four. The cyclostomes have on the whole a larger number of clefts than the true fishes. However, the hagfishes (Fig. 366) of the family **Myxinidae** have no more than six pairs, while those of the family **Bdellostomidae** (Fig. 366) have as many as fourteen pairs, and the lampreys all have seven pairs.

The direction of change in fishes appears to be one of reduction in the number of clefts from fifty or more in **Amphioxus** (Fig. 437) and **Ascidians** (Fig. 313), fourteen to six in the cyclostomes, seven to five in the true fishes, and four in the **Holocephali.**

The openings of the clefts to the exterior differ in different groups of fishes. Among the elasmobranchs each cleft usually opens separately and is not covered by any flap or operculum, although in **Chlameidoselachus,** the primitive frilled shark, each cleft has a backwardly directed flap or gill cover. In the **Holocephali** the first three clefts are covered by an operculum, and only the fourth or the last functional cleft opens freely to the outside. In the great majority of teleostomi and in the **Dipneusti** the five clefts are covered with a flap-like operculum, capable of opening and closing, thus effectively protecting the branchial filaments from injury. In some of the eels and in other specialized teleosts, the gills are completely covered with a fold of skin, the only exit being through one or two small water pores. There are two quite different and distinct kinds of gills found among fishes, namely: **external** and **internal gills.**

External gills are purely larval or embryonic organs. They are not functional in any adult fish; although their homologues are found in the perennibranchiate amphibia, believed to be **paedogenetic** or **permanent larval types.** External gills are finely branched processes of the ectodermal epithelium of the branchial tract. They are found in the embryos of many elasmobranchs and in some teleosts. A notable case of larval gills is seen in the advanced larva of **Polypterus** (Fig. 368).

The true functional gills of adult fishes are internal. They are finely divided diverticula of the endodermal epithelium of the branchial clefts. The nasal cavities are blind sacs which do not communicate with the mouth. Such communication begins with amphibia.

THE AIR-BLADDER AND ACCESSORY ORGANS OF RESPIRATION

In all of the groups of fishes above the elasmobranchs, there is a single or paired **air-bladder** (probably homologous with the lungs of higher forms), a sac-like diverticulum of the pharynx, derived from either dorsal or ventral sides of the alimentary tract. It is in all cases supplied with blood from the pulmonary artery (which, in turn, arises from the last efferent artery of either side), and, primitively at least, subserves two functions: (1) that of a hydrostatic or buoyancy organ, and (2) that of an accessory respiratory organ or primitive lung. In the most primitive teleostome fishes, the **Crossopterygii,** it is used as a lung when the water is foul; in **Amia,** it is constantly functional as an air-breathing apparatus; while in the **Dipneusti** (lung-fishes) it is an elaborately pouched lung, used to tide the fish over a period of drought.

In certain other fishes that have acquired terrestrial habits, such as the climbing perch, **Anabas** (Fig. 371), which will drown if immersed in water, and the air-breathing eel, **Clarias,** there is an extensive postbranchial chamber, provided with labyrinthine or arborescent elaborations of the epithelium that are highly vascular and play a pulmonary role.

DOGFISH

Here branchial respiration is carried on in the six pairs of branchial clefts. These branchi are primitive respiratory organs, consisting of mere diverticula of mucus membrane, richly vascular, and supported by cartilaginous processes called gill-rays. The water enters the mouth and is forced out through the gill slits. In doing so it aerates the gill filaments, and provides oxygen for the blood that circulates rapidly through them.

AMPHIBIA

External gills are found in the perennibranchiate urodeles (Fig. 374) throughout life and in practically all amphibians while in the larval stage.

The epithelium covering these external gills is ectodermal so that they are really cutaneous and not pharyngeal gills. They are, therefore, of a totally different nature from the so-called external gills of the embryos of **Elasmobranchs** and **Holocephali,** in which case the external gills are only filaments of the internal gills prolonged through the branchial openings.

Internal gills develop only in the larvae of **Anura** and are probably homologous with the internal gills of fishes, although even here the epithelium may be ectodermal. In many species of Salamanders lungs are absent, but in most amphibians they develop as ventral outgrowths from the oesophagus. The left is usually the longer. The lungs are united at their base although true bronchi are absent. In the lungless Salamanders respiration is exclusively cutaneous and pharyngeal. The lungs are supposed to have secondarily disappeared in these animals. The air ducts enter the anterior end of the lungs in amphibia, while in amniotes the lungs extend cephalad to the entrance of the bronchi which is on the medial side. This change is due to the transfer of the heart into the thorax so that the pulmonary arteries then force the bronchi toward the center of the lungs. In the amniotes the ducts have cartilage in their walls, thus being true bronchi. These bronchi often extend into the lungs where they divide into secondary and tertiary bronchi.

REPTILIA

Gills are absent, and gill-slits disappear, in all animals higher than urodeles. The lungs are large and complicated and often non-symmetrical, sometimes one is even lacking. In the snakes the lungs consist of a single sac lined with infundibula either in part or throughout. In the lizards there are one or more verticle septa dividing the lung into chambers lined with alveoli, while a part of the bronchus may extend to the extremity of the lungs. In the chameleons the septa do not reach the distal wall, consequently the chambers communicate so that the bronchus enters a cavity known as the **atrium.** This connects with the various chambers separated by the septa and these in turn open into a **terminal vesicle.** This whole structure seems to anticipate the **parabronchi**—the small uniform sized air-tubes in the lungs of birds which connect the larger secondary branches of the bronchial tubes. There develops in these lizards, long, thin-walled air-sacs from the caudal portion of the lung. These extend among the viscera, even into the pelvic region. The air sacs are used to inflate the body. In turtles and crocodiles there is no atrium and the whole lung has a spongy texture. The bronchus in turtles enters on the ventral side of the lung and not as in lizards in the medial.

Inhalation and exhalation are effected partly by drawing in the neck and thrusting it out again, thus decreasing and increasing the volume of the thoracic cavity. The air is also swallowed into the lungs by filling and then emptying the throat.

BIRDS

Birds have large lungs, each with nine small air-sacs. The air enters the bronchi and passes to the air-sacs. The air is thus warmed before being taken into the alveoli of the lungs. It makes its exit through the excurrent bronchi. A complete change of air occurs at each inspiration and expiration. The trachea and the larger bronchi are kept open by means of rings of cartilage; the trachea is enlarged, just before it divides, into a **syrinx,** or voice box (Fig. 443), a structure limited to birds, and in no way homologous with the larynx of mammals; the mechanics of voice production in the birds depends upon forcing the air through a flexible valve, which is set into vibration. The lungs also connect with visceral air-sacs, and with air-spaces in the bones.

MAMMALS

There are two points of view regarding the relationship of mammalian lungs to the respiratory apparatus of the lower forms of animals. One view holds that the lungs are merely a further development of the air-bladder of fishes, while the other insists that they are more likely to be modified gill-pouches which have grown caudally into the coelom, rather than opening to the exterior by growing laterally.

The fact, however, that the pneumatic duct is dorsal in position and the blood supply is arterial, makes the first view seem improbable. The latter view is supported by the fact that the lungs are paired outgrowths from the pharynx immediately caudal to the last gill clefts and in serial order with them. The blood supply from the sixth arterial arch would be in full accord with this view. Then, too, both in the earlier stages and in the primitive forms the skeletal support of larynx and trachea has the relations and appearance of rudimentary gill-arches and the muscles surrounding this region are modified from those of the visceral arches.

Each lung is enclosed by a pleural membrane, and the pleural cavity in which it lies, is cut off entirely from the rest of the coelom by the muscular diaphragm. This muscle usually lies transverse to the main axis of the body. It is attached close to the inner margin of the lower ribs and extends headward as a sort of tent or dome. The lungs may be divided into lobes and lobules. The right one usually has the greater number. In whales, elephants, and odd-toed ungulates there may be no lobules at all, while in the monotremes only the right lung has lobes.

From the main bronchial tube there are dorsal and ventral secondary bronchi, the ventral redividing. When the more cephalic bronchi lie in front of, or above, the pulmonary artery they are called **eparterial bronchi,** while the others are known as **hyparterial.**

Respiration is made up of Inspiration and Expiration. This has already been described in the study of the frog. Little is known regarding this process in the turtles and other reptiles. In birds the lungs are definitely attached to the ribs and vertebrae so that with every motion there is both a change in shape and size.

In the mammals the ribs lie at an oblique angle to the vertebral column. As the intercostal muscles are contracted and relaxed the ribs turn slightly and can increase and diminish the size of the thoracic cavity.

The diaphragm forms a complete partition between the thoracic and abdominal cavities and aids materially in respiration as it flattens when contracted. This increases the size of the pleural cavity and draws in air through the trachea. The abdominal muscles likewise play a part. Expiration is caused in part by the action of the intercostal and abdominal muscles, in part by the elastic tissue and smooth muscles in the lungs themselves.

ACCESSORY RESPIRATORY APPARATUS

It will be recalled that the entire respiratory tract grows from the primitive digestive tract. It is, therefore, not difficult to understand that there are certain fishes which use a more caudal portion of the digestive tract for respiration. In **Cobitis,** water is drawn in and expelled through the anal opening, the more caudal end of the digestive canal being very vascular and used in respiration.

Among the amniotes the lungs are not functional either before hatching or before birth. Still, oxygen is necessary for the development of the embryo and the carbon dioxide which has formed must have an outlet. The organ used for this combined respiratory and excretory function is called the **allantois** (Fig. 363). This is the ventral diverticulum from the more caudal part of the digestive canal, which has already been studied in Embryology. It becomes larger with the growing embryo. It is extremely vascular and is absorbed in some forms such as the Sauropsida or is drawn off with the placenta in mammals. The basal part, however, persists as the urinary bladder.

CHAPTER LIII.

THE CIRCULATORY SYSTEM

To understand the modern interpretation of the circulatory system it is necessary to have clearly in mind what is called the probable ancestral condition of this system in the lower forms of animals. Thus one may observe how in each of the succeeding higher forms, something is added to the development of the animal of the next succeeding scale below.

Some have thought that the original circulation consisted of a lymphoidal liquid alone, and as time went by this type of circulation specialized into what we now term a blood circulation. It is thus supposed that the lymph vessels, as we find them in modern forms of living animals, furnish a clue as to how the primitive systems of vessels appeared. It is all quite speculative, however. Another explanation, which has more plausibility in its favor, is that the main blood vessels are the remnants of the segmentation cavity which has become obliterated by the growth of mesoderm, the part not obliterated then becoming the blood vessels.

In any explanation that is built upon the Haeckelian "law" of biogenesis there not only remains much to be explained, but various occurrences even must **be explained away.** In this theory it is supposed that much of the race history has been lost in development, while a development of additional vessels of various kinds have covered up some of the older developmental processes.

Many blood vessels which should arise as fissures between other tissues are found to be formed as solid cords of cells. These may later form a lumen and be converted into tubes, or in other instances, vessels which originate separately in the embryo, may fuse together during development to form a single one.

There are various main points, however, which must be understood in any discussion of the blood system (Fig. 444, A, B). There is a dorsal tube carrying the blood toward the tail, from which various vessels extend toward the right and left at almost right angles through the dorsal tube. Those that pass toward the outer side of the animal are called **somatic**, those that pass toward the inner region are called **splanchnic.** These transverse vessels connect with two ventral, longitudinal tubes, one of which is in the wall of the digestive tract which runs headward and unites with the other one which has passed through the ventral body wall, so that, after the union of the two, a single tube is found coursing to the head end of the body. In one of the lowest forms of chordates, namely, **Amphioxus,** various parts of this system develop muscle walls and then act as pumping organs.

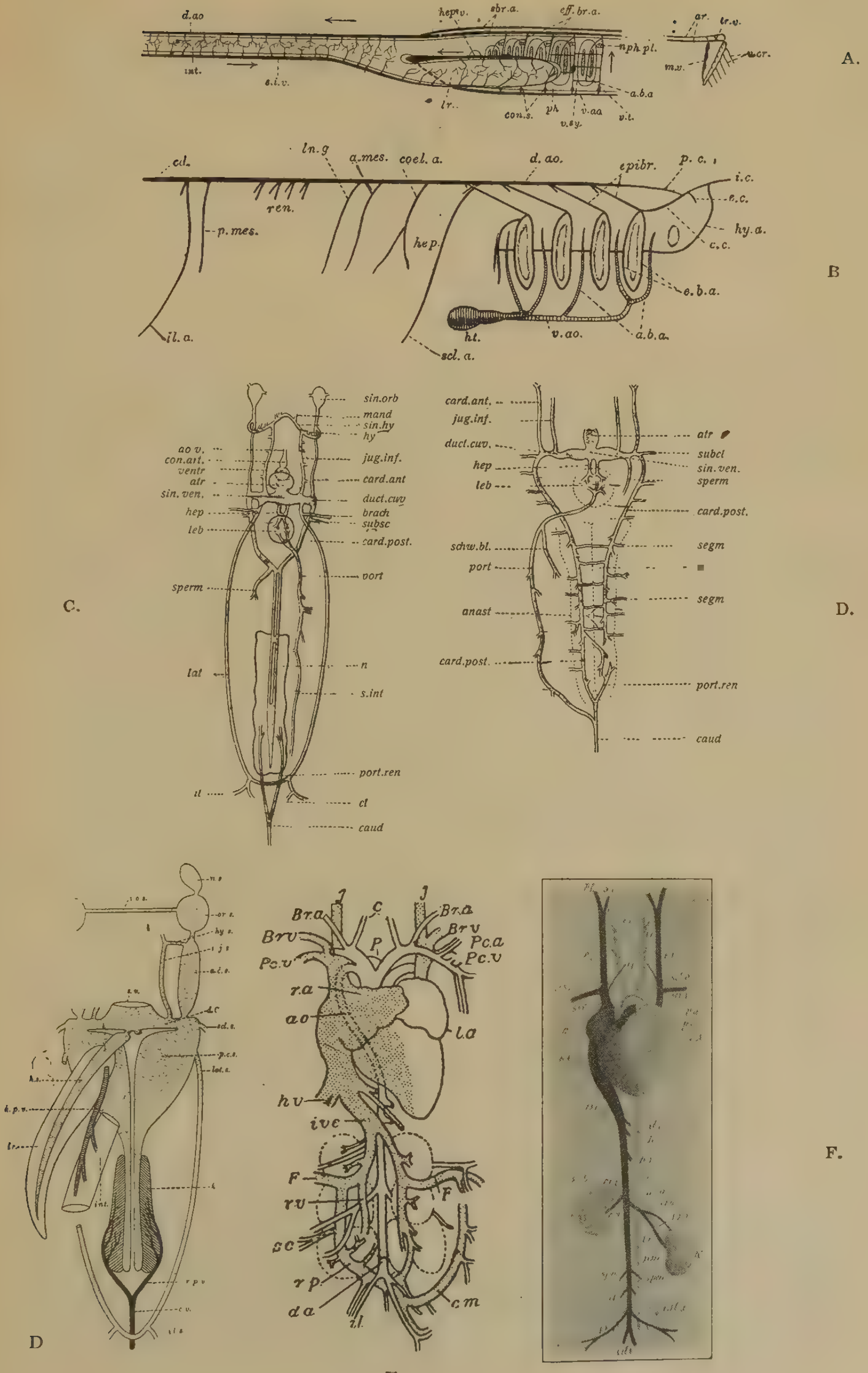
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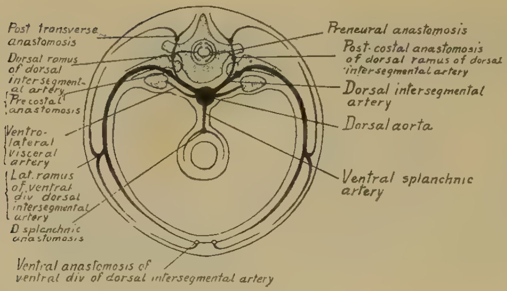
Fig. 444.


Post transverse anastomosis
Dorsal ramus of dorsal intersegmental artery
Precostal anastomosis
Ventro-lateral visceral artery
Lat. ramus of ventral div dorsal intersegmental artery
D splanchnic anastomosis
Ventral anastomosis of ventral div of dorsal intersegmental artery
Preneural anastomosis
Post-costal anastomosis of dorsal ramus of dorsal intersegmental artery
Dorsal intersegmental artery
Dorsal aorta
Ventral splanchnic artery

G.
Fig. 444.

Comparisons of Circulatory systems. *A*, a diagram of the vascular system of *Amphioxus*, from the right side. *a.b.a.*, Afferent branchial arteries; *ar.*, carotid continuations of the suprabranchial arteries; *cons.s.*, contractile swellings on the afferent branchial arteries; *d.ao.*, dorsal aorta; *eff.br.a.*, efferent branchial arteries; *hep.v.*, hepatic vein; *int.*, intestine; *lr.*, liver; *m.v.*, "moniliform" vessel from left carotid; *nph.pl.*, nephridial plexus; *ph.*, pharynx; *s.i.v.*, subintestinal vein; *sbr.a.*, suprabranchial arteries; *tr.v.*, transverse vessel joining the carotids; *v.ao.*, ventral aorta; *v.cr.*, vessels of cirri; *v.sy.*, vessels of synapticulæ; *v.t.b.*, vessels of tongue-bars.

B, A diagram of the arterial system of a dogfish, seen from the right side. *a.b.a.*, Afferent branchial arteries; *a.mes.*, anterior mesenteric artery; *c.c.*, common carotid artery; *cd.*, caudal artery; *coel.a.*, cœliac artery; *d.ao.*, dorsal aorta; *e.b.a.*, efferent branchial arteries; *e.c.*, external carotid artery; *epibr.*, epibranchial arteries; *ht*, heart; *hep.*, hepatic artery; *hy.a.*, hyoidean artery (this joins the internal carotid of the opposite side, which is not shown); *i.c.*, internal carotid artery; *il.a.*, iliac artery; *ln.g.*, lienogastric artery; *p.c.*, posterior carotid artery; *p.mes.*, posterior mesenteric artery; *ren.*, renal arteries; *scl.a.*, subclavian artery; *v.ao.*, ventral aorta. (From Borradaile.)

C and *D*, Comparison of the venous systems of the dogfish and a teleost. *anas*, anastomosis between the two posterior cardinals; *ao.v.*, ventral aorta; *atr*, atrium; *brach*, brachial vein; *card.ant.* and *card.post.*, anterior and posterior cardinals; *caud*, caudal vein; *cl*, cloacal vein; *con.art.*, conus arteriorsus; *duct.cuv.*, duct of Cuvier; *hep*, hepatic vein; *hy*, hyoid vein; *il*, iliac vein; *jug.inf.*, inferior jugular vein; *lat*, lateral vein; *leb.*, liver; *mand.*, manibular vein; *n.*, kidney; *port.*, hepatic portal vein; *port.ren.*, renal portal vein; *segm.*, segmental veins; *s.int.*, subintestinal vein; *sin.hy.*, hyoid sinus; into which the veins from the mandibular and hyoid arches open; *sin.orb.*, orbital sinus; *sin.ven.*, sinus venosus; *sperm*, spermatic vein; *subsc.*, subscapularis vein; *subcl.*, subclavian vein; *schw.bl.*, veins of the swim-bladder; *ventr.*, ventricle. (Both figures from Boulenger, A after Parker.)

D, A diagram of the venous system of the dogfish. *a.c.s.*, Anterior cardinal sinus; *c.v.*, caudal vein; *d.C.*, ductus Cuvieri; *h.p.v.*, hepatic portal vein; *h.s.*, hepatic sinus; *hy.s.*, hyoidean sinus; *i.j.s.*, inferior jugular sinus; *i.o.s.*, interorbital sinus; *il.s.*, iliac sinus; *int.*, intestine; *k.*, kidney; *lat.s.*, lateral sinus; *lr.*, liver; *n.s.*, nasal sinus; *or.s.*, orbital sinus; *p.c.s.*, posterior cardinal sinus; *r.p.v.*, renal portal vein; *s.v.*, sinus venosus; *scl.s.*, subclavian sinus. (From Borradaile.)

E, A diagram of the principal arteries and veins of a pigeon. *ao.*, Aortic arch; *Br.a.*, brachial artery; *Br.v.*, brachial vein; *C.*, carotid artery; *c.m.*, coccygeo-mesenteric vein; *d.a.*, dorsal aorta; *F.*, femoral vein adjoining femoral artery; *h.v.*, hepatic veins; *il.*, internal iliac artery and vein; *i.v.c.*, inferior vena cava; *j.*, jugular vein; *l.a.*, left auricle; *P.*, right pulmonary artery; *Pc.a.*, pectoral artery; *Pc.v.*, pectoral vein; *ra.*, right auricle; *rp.*, hypogastric vein; *rv.*, renal vein; *sc.*, sciatic artery and vein. Near the apex of the ventricle the cœliac and anterior mesenteric arteries and the epigastric vein are shown, but not lettered. At the hinder end of the figure the caudal and posterior mesenteric vessels are shown, but not lettered.

F, The circulatory system of the rabbit. (*a*) Letters to right—*e.c.*, External carotid; *i.c.*, internal carotid; *e.j.*, external jugular; *scl.a.*, subclavian artery; *scl.v.*, subclavian vein; *p.a.*, pulmonary artery (cut short); *p.v.*, pulmonary vein; *L.A.*, left auricle; *L.V.*, left ventricle; *d.ao.*, dorsal aorta; *h.v.*, hepatic veins; *c*, cœliac artery; *a.m.*, anterior mesenteric; *s.r.b.*, suprarenal body; *l.r.a.*, left renal artery; *l.r.v.*, left renal vein; *K*, kidney; *p.m.*, posterior mesenteric artery (incorrectly shown as if paired); *spm.*, spermatic arteries and veins; *c.il.a.*, common iliac artery. (*b*) Letters to left—*p.f.* and *a.f.*, posterior and anterior facial; *e.j.*, external jugular vein; *i.j.*, internal jugular; *R.Scl.*, right subclavian artery; *S.V.C.*, superior vena cava; *R.A.*, right auricle; *R.V.*, right ventricle; *I.V.C.*, inferior vena cava; *r.r.a.*, right renal artery; *r.r.v.*, right renal vein; *s.r.b.*, suprarenal body; *spm.*, spermatic arteries and veins; *il.*, ilio-lumbar vein; *f.v.*, femoral or external iliac vein; *i.il.v.*, internal iliac veins. (From Thomson.)

G, Diagram of intercostal (intersegmental) arteries.

In all vertebrates the heart lies on the ventral side of the digestive tract covered by a pericardial sac. This sac is really a part of the coelomic lining. The various large blood vessels carrying blood from the heart to the general system are known as **aortae,** and the large veins returning the blood directly into the heart are usually called **venae cavae.**

The ventral aorta gives off various pairs of vessels called the **aortic arches,** which are situated on each side of the pharynx in the grooves called the **gill septa.** These arches run from the ventral aorta around the digestive canal to the dorsal side where they unite to form a longitudinal canal. That is, the arches along each side form a separate canal at first, then the two canals unite to form the dorsal aorta, which runs caudad the entire length of the body. There may be, and usually are, various small arteries arising from any or all of these arterial arches. It is necessary that the student know **what becomes of the aortic arches** and in what groups of animals certain ones disappear and others remain functional. The **first pair** of arches lying toward the head end give rise to both the **internal carotid artery** which goes to the brain, and the **external carotid** supplying the more superficial portion of the head. The arteries which arise from the dorsal aorta are either **somatic or splanchnic,** that is, either supply outer or internal portions of the body. Examples of somatic blood vessels are the **intercostal** (intersegmental) **arteries** running between the ribs, while the **mesenteric arteries,** which are distributed primarily to the alimentary canal, are of the splanchnic type.

The **subclavian artery,** which supplies the arms of the animal, and the **iliac artery,** which supplies the hind limbs, are some of the larger and more common of the somatic arteries.

The splanchnic or visceral arteries do not show much trace of segmentation. They are distributed to the walls of the digestive tract. Two pairs, however, of these vessels are of special importance, namely, a pair of **omphalomesenteric arteries** in front, and a pair of **hypogastric arteries** (internal iliac) near the origin of the iliac arteries (Fig. 450).

There are really no **end arteries** or veins. All arteries carry blood to certain parts of the body through minute capillaries which then anastamose with the venous capillaries which drain the various parts which the arteries supply.

The head is drained by a pair of **jugular veins** which are found above the mouth. In fishes there are also a pair of **inferior jugulars** in the region of the lower jaw and the lower side of the gill arches. These run caudad to the level of the **sinus venosus,** where they are joined by a **post cardinal** coming from the excretory organs. The jugular and post cardinal on each side unite to form a trunk which runs transversely and empties into the sinus venosus. This is called the **Cuvierian duct.** A pair of **omphalomesenteric veins** enters the sinus venosus from the caudal side. These are continuations of a **subintestinal vein** running alongside of the liver after having passed along the ventral side of the digestive tract. This subintestinal vein forms a loop around the anal opening and extends to the end of the tail as the **caudal vein.** The **subclavian vein** from the arm may empty either into the jugulars or the post cardinal near the Cuvierian duct. The blood from the hind limb leaves by an **iliac vein** on each side, runs forward on the lateral body wall and is called the **lateral abdominal vein.** This also enters the Cuvierian duct.

Omphalomesenteric and subintestinal veins belong to the visceral or splanchnic group. The others are somatic. The vessels mentioned are important, and should be known thoroughly because they develop very early in the embryo, and, practically all later developments as well as modifications that take place in them, can only be discussed intelligently when the basic structures just mentioned are known. There is probably no more variable system in the body (even in the same species) than the vascular.

DETAILED STUDIES

THE HEART

The heart itself is a **muscle** having a distinctive cellular structure, this being a sort of "cross" between voluntary and involuntary muscle, the muscle fibers are striated but run in a **syncitial form** (Fig. 23). The muscular walls of the heart itself are known as **myocardium.** The inner layer of the heart, corresponding to the endothelium of the blood vessels and continuous with them, is called **endocardium,** while the covering of the heart is known as the **pericardium.** Lying between the myocardium and the pericardium is a serous liquid called **pericardial fluid.**

We have already discussed a part of the embryonic method of heart development, but it is necessary here to enter into more detail. The lateral plates of the walls of the coelom grow centrally beneath the digestive canal. There are four regions discernible in these lateral plates, namely, the splanchnic or visceral, the mesenterial and somatic walls, as well as the coelomic cavity.

Between the coelomic walls and the endoderm one may observe various cells called **vascular cells.** It is supposed that they find their origin from the mesothelium. Those that lie most dorsalward assist in forming the dorsal blood vessels, while those lying ventrad contribute to the heart and the ventral trunks. The two lateral plates just mentioned continue until they meet in a ventrad region. This forms the **ventral mesocardium** (Fig. 344). A little later the dorsal region comes together forming the **dorsal mesocardium,** so that now, that which was formerly a groove has become **a definite tube.** The ventral fusion has disappeared, leaving the dorsal part attached and causing the two coelomic cavities to unite, forming the **pericardial cavity.**

In turtles and crocodiles there is a small portion of this ventral mesocardium remaining which connects the apex of the heart to the pericardial wall. The walls of this tube are now called the **myoepicardial mantle** and the vascular cells which are enclosed within this mantle are those which form a continuous sheet and become the endocardium or lining of the heart.

There are still some vascular cells cephalad and caudad to this tubular heart. These furnish a lining for the blood vessels which arise from the edges of the lateral plates and connect with the heart. The first vessels toward the head end (the **anterior pair)** become the **mandibular arteries,** while those vessels lying caudad to the heart (the posterior) are called the **omphalo-mesenteric veins.**

It is at this time also that immediately cephalad to the omphalo-mesenteric vein a transverse tube appears on each side connecting with the heart tube, and it is these tubes which are the ducts of Cuvier. The ridge where the Cuvierian ducts grow, becomes larger until it forms a transverse partition known as the **septum transversum** (Fig. 348). It is this septum or partition which separates the heart cavity or pericardial region from the abdominal or peritoneal cavity. In the myxinoids and elasmobranchs this septum never completely closes dorsally, but leaves one or two openings known as the **pericardio-peritoneal canal.**

Where the early embryo is closely appressed to the very large yolk sac, as in the bony fishes and in all amniotes, the development of the heart is modified. The pharynx is not complete below at first, but communicates ventrally with the yolk. The two hypomeres are thus prevented, for a time, from meeting ventrally. "Each, however, is accompanied by its vascular cells; its edge becomes grooved and the grooves are rolled into a pair of tubes, lined with endocardium, so that for a time the anlage of the heart consists of two vessels (Fig. 283), each connected in front and behind with its own mandibular artery and omphalo-mesenteric vein, and is surrounded with its pericardial sac. Later the two tubes approach and fuse with the formation of mesocardia as before: these latter soon disappear, leaving the whole much as in the small-yolked forms."

While the pericardium is relatively large at first, in adult forms it is usually quite close fitting to the heart when the heart is expanded.

It must not be forgotten that in **systole** the heart contracts and becomes considerably smaller than normal; that in **diastole** it expands and attains its full size, filling the pericardium accordingly.

It can readily be understood that as long as the mesocardia are present the heart tube will be a straight canal connected with the pericardial sac in front and behind. However, as the mesocardia entirely disappear in due time and the heart tube continues to grow, it bends upon itself something like a capital letter "S," the bending or flexure being largely in a vertical plane (Fig. 283).

At the middle point of the bend the tube remains quite small and here is formed what is called the **atrio-ventricular canal** (Fig. 445). It is in front and behind this canal that the walls become thickened and the lumen enlarged. The caudal end, which is also the dorsal in this case, forms the chambers known as the **atrium** or **auricle.** The ventral end becomes the **ventricle.** Caudad in the atrium, there is a constriction forming a second chamber called the **sinus venosus** and it is into this that the Cuvierian duct and the omphalo-mesenteric vein enter. The ventral parts of the heart-tubes also form a smaller trunk called the **truncus arteriosus,** while the **ventral aorta** connects this portion of the heart with the **mandibular arteries** already mentioned.

While the heart is really a muscle, or rather many interwound bundles of muscles, there are certain parts such as the **sinus venosus** where the muscle cells themselves are somewhat scanty as compared with other parts of the heart.

The endocardium develops folds or **valves** (Fig. 445) in certain places so that blood may flow forward but not backward, and this valvular part of the truncus is known as the **conus arteriosus.** In the vertebrates this conus is reduced to a single row of valves with the exception of the elasmobranchs, ganoids, and amphibia. The valves lie between the auricle and the ventricle and are prevented from being pushed up into the auricle (when the heart contracts and immense pressure is brought to bear upon them) by little ligaments called **chordae tendineae,** which extend from the edges of the valve to the opposite wall of the ventricle. They are kept taut during systole by capillary muscles called **columnae carneae.** There is also a valve between the auricle and the sinus in some vertebrates where the hepatic vein enters into the sinus.

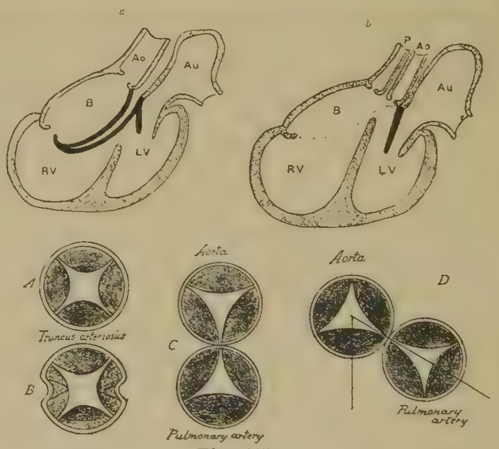


Fig. 445.

A and *b*, Reduction of the bulbo-ventricular fold of the heart. *Ao*, aortic bulb; *Au*, atrium; *B*, bulbus cordis; *RV*, right ventricle; *LV*, left ventricle; *P* (in *b*) pulmonary artery. (After Keith.)

A, B, C, D, Scheme showing division of bulbus cordis and its thickenings into aorta and pulmonary artery with their valves. The division begins in *B*, the lateral thickenings dividing respectively into *a*, *c*, and *c.f.* Rotation from right to left shown in *D*. (After Heisler.)

If the conus arteriosus is followed by a strong muscular region this is called the **bulbus arteriosus.** The bulbus is composed of regular heart muscle, while the truncus is composed of muscle like the rest of the blood vessels. It is for this reason that both conus and bulbus are regarded as a part of the heart, while anything cephalad to these is considered a part of the ventral aorta.

THE VASCULAR SYSTEM

After food has been taken into the digestive tract and digested and the little villi of the small intestines have absorbed the semi-liquid food, this newly absorbed food is ready to become a part of the blood. An elaborate system of blood vessels with a wonderfully intricate and elaborate pumping apparatus—the heart—carries this nourishment to every part of the body.

Before taking up the development of this system, known variously as **circulatory** or **vascular,** it is necessary that the student understand quite thoroughly what the adult organs are like and what their function is. Only then may one validly attempt to ascertain how and why the organs are placed where they are and how and why the function is what it is. The central part of the vascular system is the heart. In the mammal this consists of four definite chambers—**two auricles** at the broad end of the heart, and **two ventricles** toward the lower or apex region. The structure of the heart itself is muscular. The compartments of the heart and the work they do belong to the circulatory system proper and will be described here.

Every blood vessel **leaving the heart,** no matter whether it carries arterial or venous blood, is called an **artery,** and every blood vessel **entering the heart** is called a **vein.** This distinction must be kept very clear.

Then, too, it must never be forgotten that blood entering the heart through a vein **always enters a sinus** or **auricle.** This auricle acts as a reception-chamber for all blood entering the organ. After the blood has entered this chamber it passes downward through an opening into one of the ventricles, and it is **from the ventricle** that the blood leaves the heart.

In the higher forms of mammals, such as man (Fig. 445), blood enters the right auricle through the large **venae cavae,** then passing downward through the **auricular-ventricular opening** into the right ventricle. From here it passes through the **pulmonary artery** to the lungs to be **aerated** (that is, to be thoroughly mixed with oxygen and to lose the carbon dioxide that it has gathered in draining the entire body). After being aerated, the blood passes back to the left side of the heart through the **pulmonary vein** to enter the left auricle, and then passes down through a **left auricular-ventricular opening** into the ventricle from which it sends forth the blood stream through the **aorta** to all parts of the body, supplying the parts with food and nourishment.

The system just described is known as the **systemic** because the blood which leaves the heart **through the aorta** nourishes all parts of the body.

The arteries break up into smaller **arterioles** and **capillaries.** The liquid part of the blood is called **blood-plasma** as long as it is contained

within the blood vessels, and **lymph** as soon as it has seeped through the walls of the blood vessels and bathed the surrounding tissues. It is gathered up from here by the various lymphatic vessels which unite to form the large **lymph duct.** This duct empties into one of the veins of the neck. The blood which has remained within the blood vessels and passed through the capillaries is taken up by the venous capillaries and passes toward the heart either directly or indirectly through a **portal system.**

It is essential that one appreciate that the arteries **supply** all parts of the body with nourishment and that the veins do the **draining.** It follows, then, that the arteries begin as vessels of some size and become smaller and smaller as the blood supply from the heart becomes distributed more and more, while veins begin as capillaries and continually increase in size. An artery and a vein often lie side by side, but the **blood current** in the vessels is running in an opposite direction.

In addition to the systemic circulation there is also the **pulmonary circulation,** which is the name given to the blood stream leaving the right ventricle of the heart, passing through the **pulmonary arteries** to the lungs, and after being aerated **returning, through the pulmonary veins,** to the left auricle, from whence it flows downward into the left ventricle and is then again ready for the systemic circulation.

Whenever a vein splits up into capillaries so that the venous blood must pass through an organ on its way back to the heart (either to have waste substances removed as in the kidneys or to take up new substances as in the liver), and this blood is then again collected by venous capillaries and sent on its way, a **portal system** is formed.

The **renal-portal** system and the **hepato-portal** system are the two important ones in the body's economy.

When the circulatory system of the frog was discussed it was stated that one must not forget that the material with which the heart works is **blood,** but that the heart is similar to a pump or an engine, and, that, consequently, just as a pump or an engine which is used for the purpose of forcing water through a great hydraulic system requires water in two places and in two ways to continue its work, so the heart requires blood in two places and in two ways to do its work.

The engine requires water in its boiler so that steam can be produced. This steam then supplies the force for its work of pumping water, let us say, through the water-pipes of the building in which it is installed. So, too, the heart must have a blood supply to furnish it with energy just as the engine requires water to manufacture its steam. Therefore, there are blood vessels running into the heart-walls and into the walls of blood vessels themselves so as to furnish these with material to produce the required energy to continue their pumping power. The blood vessels that supply the heart walls are known as **coronary vessels.** The coronary arteries leave the aorta immediately after the aorta, in turn, has left the left ventricle. The blood vessels in the walls of blood vessels are known as **vasa-vasorum.**

It is essential that these two systems be kept separate and distinct. The mere pouring of blood into the cavities of the heart is equivalent to the water in the tank of an hydraulic system, while the blood which enters the heart muscle itself is equivalent to the water in the engine's own boiler that furnishes the steam from which the energy, in turn, comes that makes pumping possible.

This analogy may be carried a little further; for, just as the water in the hydraulic system, if it be used for drinking purposes, must be **filtered,** so, before the blood, which is pumped through the vascular system, can be used again, it must likewise be filtered. This is the work of the **portal systems.**

A final point is to be borne in mind, before taking up the circulatory system in detail, is that the **vertebrate circulatory system** is known as a **closed circulation,** as contradistinguished from the **open system** seen in some of the lower forms of animals such as the crayfish.

What is meant by a **closed system,** is that the blood from the time it leaves the heart, until it returns, is always in **direct communication** by means of arteries, capillaries and veins There are no open spaces through which the blood can pass out of these vessels. A seeming exception is the lymph. This does not pass through an opening, however, but seeps directly through the walls and bathes all parts of the **intercapillary region.**

DEVELOPMENT

Everyone knows that the mammalian heart has its point or apex to the left, but the student must know how this has come about. He must also know why it is that, just as with the digestive tract, certain nerves which lie in the right and left side of the early embryo, come to lie on the dorsal and ventral sides in the adult. The heart, like the digestive tract, grows something on the order of a straight tube, although made up of separate cephalic and caudal ends which have become fused together. As the embryo continues developing, the heart turns to the left, so that the nerves which lie upon the right side will now be ventral and those which lie upon the left side will be dorsal, while the right auricle and ventricle which have been brought ventral by this turning to the left now occupy almost the entire ventral portion of the heart, the left auricle and ventricle being dorsal. It is for this reason that a very small portion of the left auricle and ventricle can be seen from the ventral side of the body. It will be remembered that in the embryo of the chick we spoke of mesoblastic cells which were derived from three separate sources. One source of these is from the primitive streak. The second source is from that scattered group of cells that was left between the ectoblast and entoblast when the entoblast became a distinct layer of cells. Thirdly, in the middle and lateral parts of the area pellucida, cells are budded off from the upper side of the entoblast to become mesoblast, at about the very time the primitive streak is forming.

Now, all of these mesoblastic cells together unite to form a continuous layer. This layer continues expanding until it passes beyond the boundaries of the area pellucida and forms a middle layer in the inner zone of the area opaca. This zone is the **vascular area** (Fig. 264). It is in this area that the blood vessels begin to form. This occurs in the chick on the very first day. A network appears in the entire vascular area which surrounds the embryo. Here irregular reddish blotches are formed which are called **blood islands**, and it is from these blood islands that the red corpuscles are formed. This network develops into a system of cords, at first solid, but soon a **lumen** is acquired and, as the vessels unite, there is a continuous but indefinite blood vessel formed. The very first vessel which becomes definitely shaped so that it can be recognized as a part of the vascular system is formed around the entire vascular area as a sort of boundary and is called the **sinus terminalis.** (Fig. 284, C.)

The blood islands appear in cross section as little local thickenings on the dorsal walls of the blood vessels. These bud off into the cavities of the vessels and form the first blood corpuscles, and it is supposed that from these all the colored corpuscles of the blood are descended.

The network of vessels continues to grow, some of the vessels later becoming arteries, some veins, and still others remain small as capillaries. These unite and extend **toward the embryo,** while, within the embryo proper, there has been a growth of the vascular system also, which has extended outward **toward this vascular area.** All these vessels unite to form the entire vascular system.

Larger vessels of the vascular area unite with the posterior end of the heart which by this time has already commenced to beat. The other vessels unite with the anterior or cephalad end of the heart and these become the arterial system, so that by the end of the second day, in the chick, a complete vascular system has already been formed with a beating heart.

At first the heart consists of only two longitudinal vessels which are connected at the cephalic end. These spread out caudad like an inverted "V" (Fig. 283). The arms of this "V" shaped portion soon fuse together and look like an inverted "Y." The cavities of these two fusing tubes remain apart for some time and then form **one cavity.** That is, the endothelial lining remains separate as two distinct cavities after the muscular walls have united.

On the dorsal surface the muscular walls are incomplete also for a short time, but after complete fusion the walls also are completed. It is the stem of this "Y" which forms the heart. The two diverging arms of the "Y" unite, or rather have united some time before this, so that they are continuous with the large **vitelline veins** which bring the blood back to the heart from the vascular area.

The heart is now a **short straight tube** attached to the ventral wall of the pharynx and consists of the muscular, united part of this "Y," the two arms being the ends of the diverging vitelline veins which run backward or caudad at the hindermost angle of the head fold. As this fold is pushed farther and farther back, the straight part of the "Y" is naturally pushed back also and lengthened. Not only this, but this **straight part** of the heart **grows more rapidly** than does the place to which it is attached, so that it does not even find room enough to continue its growth with the heartfold, but must bend into a loop with its convexity toward the right side of the embryo. The heart has now lost its attachment to the pharynx (with exception of its two ends). The caudal end of the heart, in which the vitelline veins empty, is called the **venous**; the cephalic end the **arterial end** of the heart. Beating of the heart begins as soon as a connection has been made between this "Y" shaped tubular vessel with the vessels which have been formed in the vascular area. The palpitation starts at the venous or caudal end and passes to the arterial or cephalic end. The palpitation of the heart already begins before one can distinguish any definite muscular tissue which has developed from the mesoblast.

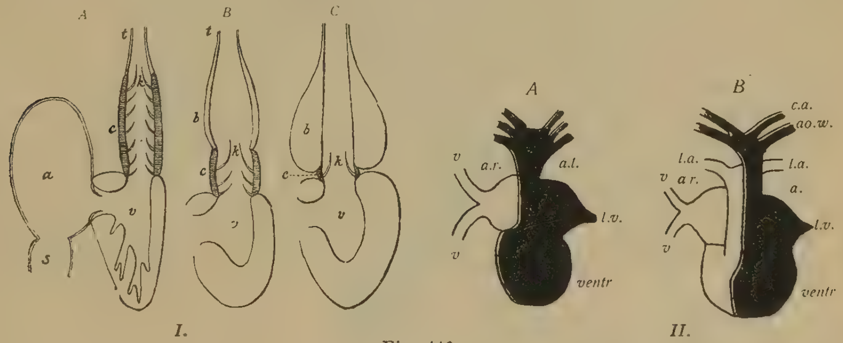


Fig. 446.

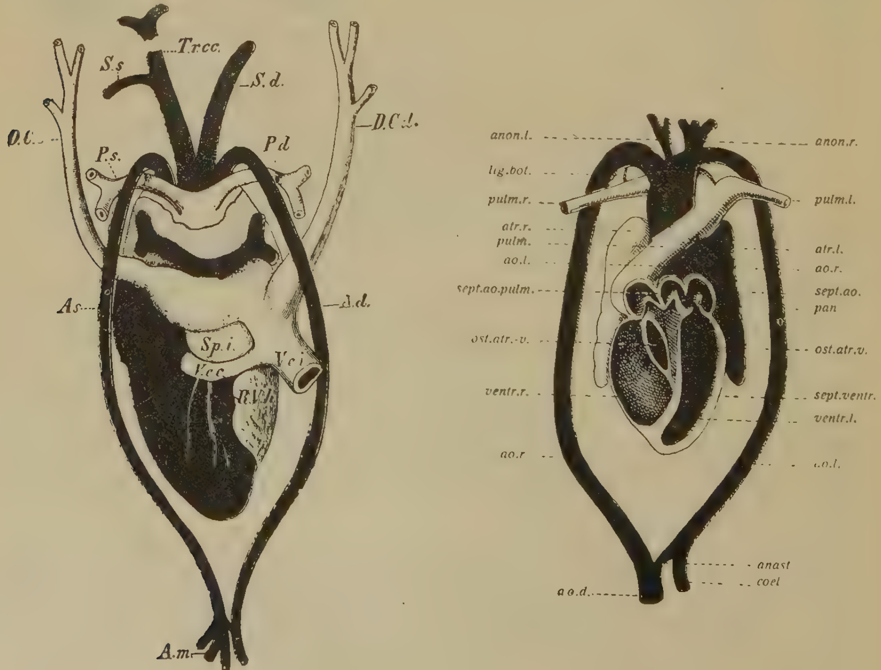
I, Schematic longitudinal sections of the heart. *A*, *dogfish*, *B*, *Ganoids*, and *C*, *Teolosts*. *a*, atrium; *b*, bulbus arteriosus (an enlarged portion of the truncus arteriosus); *c*, conus arteriosus; *k*, valves; *s*, sinus venosus; *t*, truncus arteriosus; *v*, ventricle. (After Boas.)

II, The circulatory system in the amphibians. *A*, *Urodele*, and *B*, *Anura*. *a.l.* and *a.r.*, left and right atria; *ao.w.*, aortic root (radice); *ca.*, carotid arteries, which spring from the conus arteriosus together with the *ao.w.*; *l.a.*, pulmonary arteries which carry venous blood from the ventricle to the lungs; *l.v.*, pulmonary veins which carry arterial blood to the left atrium; *v*, the veins which carry venous blood from the general body system to the right atrium; *ventr*, ventricle. (From Schimkewitsch after Wiedersheim.)

The arterial end of the heart is known as the **bulbus arteriosus.** From this, two narrow vessels, the aortic arches, pass around the digestive tract to the dorsal side, turning caudad and becoming the **dorsal aortae.** These two dorsal aortae run along each side of the notocord under the mesoblastic somites and pass toward the tail unconnected with each other, but just before reaching the tail a large branch is given off, in fact, the branch is much larger than the aorta itself from which it arises. This large branch is called the **vitelline artery.** It is the vitelline arteries that carry the blood back to the vascular area from which it was brought by the vitelline veins.

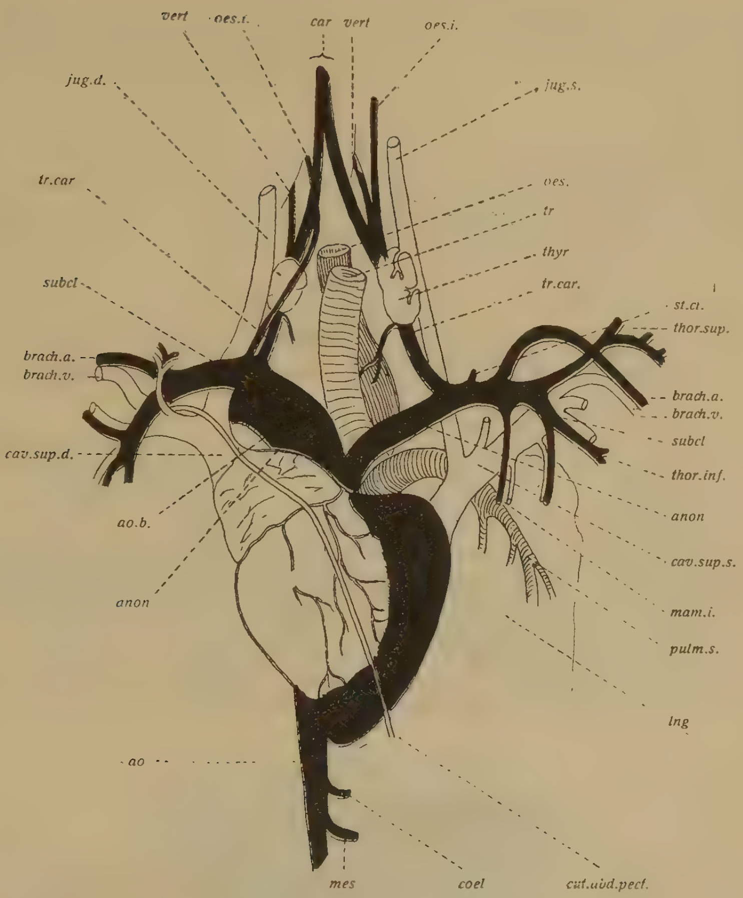
The heart we have just been describing is that of the chick. In cyclostomes and fishes (except the dipnoi) there is what is known as a **branchial** or **venous heart** (Fig. 446). All of the blood which enters such a heart is venous blood. This venous blood is pumped directly to the gills where it loses its carbon dioxide and takes up oxygen before being distributed to the various parts of the body. The important thing to note is that in such cases the blood only passes through the heart **once** in making its complete circuit. It is not, however, correct to consider the embryo of higher forms as being the same as this type of "one-heart-circulation," for only oxygenated blood passes through the heart in such embryos when it is in this stage.

In the dipnoi and amphibia (Fig. 446), where lungs are formed which take up part of the work of the gills, the heart divides in an **arterial** or **systemic** and a **venous** or **respiratory half.** This division is caused by a **septum** or partition in the auricle which divides the chambers. It will be remembered that blood always enters through a vein and always enters into a sinus or an auricle of the heart. The venae cavae which return the systemic blood to the heart, therefore, empty



A. B.

Fig. 447.



C.

Fig. 447.

Comparisons of heart and connecting blood vessels in the crocodiles and birds. *A*, Dorsal view of Crocodilian heart. *A.M.*, mesenteric artery; *Ad* and *As*, aortic arches; *D.C.d.* and *D.C.s.*, right and left ducts of Cuvier; through which the venae cavae enter the heart; *LV.*, pulmonary veins; *L.V.h.* and *R.V.h.*, left and right atria; *P.d.* and *P.s.*, right and left pulmonary arteries; *S.d.* and *S.s.*, right and left subclavian arteries; *Sp.i.*, region of the interseptal valves; *Tr.cc.*, common carotid artery; *V.c.c.*, Coronary vein; *V.c.i.*, inferior vena cava. (After Röse.)

B, Ventral View of Crocodilian Heart. *anast.*, so-called dorsal anastomosis of the two roots of the aorta; *anon.l.* and *anon.r.*, left and right innominate trunks; *ao.l.*, left aortic arch; *ao.d.*, dorsal aorta; *ao.r.*, right aortic arch; *atr.l.* and *atr.r.*, left and right atria; *coel*, coeliac artery; *lig.bot.*, Botalli's Ligament *ost.atr.v.*, atrio-ventricular opening; *pulm.*, pulmonary artery; *pan.*, foramen of Panizzae; *sept.ao.*, aortic septum; *sept.ao.pulm.*, aortic-pulmonary septum; *sept. ventr.*, ventricular septum; *ventr.l.* and *ventr.r.*, left and right ventricle. (After Greil.)

C, Heart and communicating vessels of bird. (Swan). *anon*, innominate artery; *ao*, aorta; *ao.b.*, aortic arch; *brach.a.* and *brach.v.*, brachial artery and vein; *car*, carotid artery; *cav.sup.a.* and *cav.sup.s.*, right and left superior venae cavae; *coel*, coeliac artery; *cut.abd.pect.*, cutaneous abdominal-pectoral vein; *jug.d.* and *jug.s.*, right and left jugular veins; *lng*, lung; *mam.i.*, internal mammary artery; *mes*, mesenteric artery; *oes*, oesophagus; *oes.i.*, inferior oesophageal artery; *pulm.s.*, left pulmonary artery; *st.cl.*, sternoclavicularis artery; *subcl*, subclavian artery; *thor.inf.* and *thor.sup.*, thoracalis ( ) inferior and superior arteries; *thyr*, thyroid gland; *tr*, trachea; *tr.car.*, carotid trunk; *vert*, vertebral artery. (After Gadow.)

into the right auricle, while the pulmonary veins which carry blood from the lungs to the heart enter the left auricle. As this blood which has returned from the lungs is now oxygenated and ready for distribution to the general system, it is the **left side** of the heart which becomes the **arterial side.**

In the higher forms the ventricle is also divided by a septum. The valves on the right side which separate the auricle from the ventricle are called the **tricuspid valves,** while those on the left side separating the left auricle and left ventricle are known as the **mitral** or **bicuspid valves.**

In the crocodiles there is an opening between the two sides of the aortic trunk known as the **foramen Pannizae** (Fig. 447, B. pan), so that there is really some mixture of arterial and venous blood in these animals.

The separation into **four compartments** is complete in birds and mammals (Figs. 445, 447, C), so that the blood must pass through the heart twice. Once through the venous, and once through the arterial half, in order to make a complete circuit of the body.

The heart is formed directly behind the mandibular artery which is the first aortic arch (Fig. 309), so that as other vessels grow, it is forced back further and further until it lies ventrad and caudad to the pharynx, while in the adult higher forms of mammals it is carried back as a result of this unequal growth even into the thorax. (The extreme of migration being seen in the giraffe and the long-necked birds.)

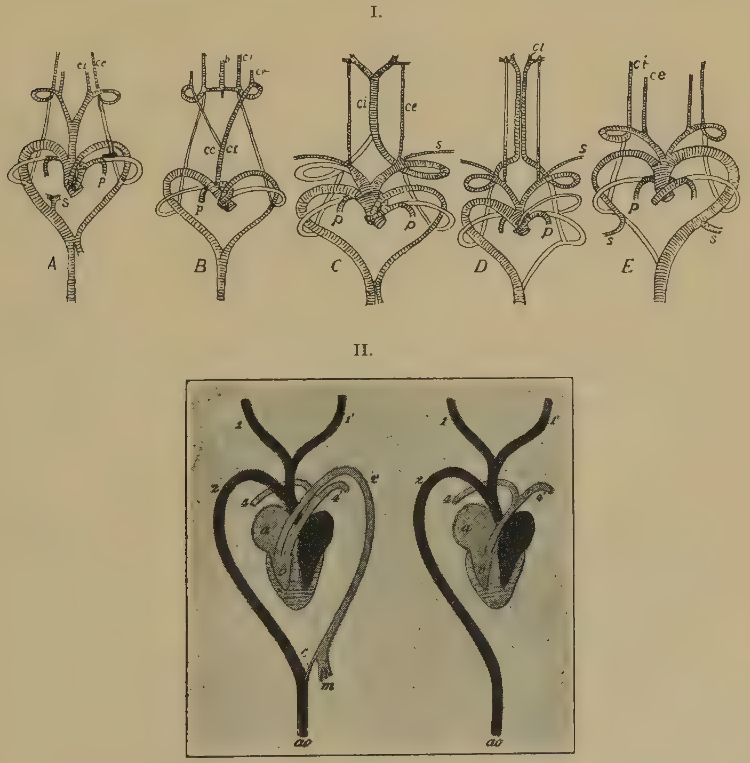
THE ARTERIES

AORTA AND AORTIC ARCHES

The ventral aorta is that large artery running headward from the heart. It extends to the mandibular artery, which is another name for the first aortic arch (Fig. 309). The mandibular arteries, like other arches, pass dorsad (one on each side of the pharynx) until they meet and form a pair of dorsal longitudinal tubes called the **radices aortae.** Between the first aortic arch (mandibular artery) and the heart there arise some six or more pairs of arches similar to those forming the mandibular artery. The number of such arches depends upon the number of gill-clefts the animal has, for these arches develop in the septum between the gill-clefts. (The number of arches is greater in the myxinoids where the number of clefts varies; seven or eight in the notidanid sharks; and, as recent investigations tend to show, probably six in the embryos of all other vertebrates.)

As the embryo continues to grow, the number of these arches, which remain or degenerate, seems to be influenced to a considerable extent by the various changes of the respiratory system the particular animal in question may develop. When gills develop, each aortic arch divides into two portions. An **afferent branchial** artery which carries the blood from the ventral aorta **to the gills** and an **efferent branchial artery** which carries it **from the gills** to the radix aortae. Both afferent and efferent vessels run parallel to each other for a part of their course, and are connected with each other by numerous capillary loops running through the gill filaments. As the blood passes through the gills it loses its carbon dioxide and takes up oxygen so that it is changed from venous to arterial blood. In all animals that develop an amnion one cannot distinguish between afferent and efferent branchial arteries, the aortic arches running directly from the ventral aorta to the dorsal longitudinal radices aortae.

With the possible exception of cyclostomes, no gills are ever developed in the region of the first arch, so no afferent and efferent vessels



I.

II.

Fig. 448.

I, Aortic arches of amniotes. Compare with Figure 309. *A*, African Lizard (*Varanus*); *B*, Snake; *C*, Alligator; *D*, Bird; *E*, Mammal. *b*, basilar artery; *ec*, common carotid; *ei*, *ce*, internal and external carotids; *da*, dorsal aorta; *p*, pulmonary, *s*, subclavian. (From Kingsley after Hochstetter.)

II, Comparison of Heart and aortic arch of crocodile and bird. *a*, right auricle; *a'*, left auricle; *ao*, descending aorta; *c*, small connecting vessel; *m*, intestinal branches. (*c* and *m*, before they separate, form the left aortic arch); *v*, right ventricle; *v'*, left ventricle; 1 and 1', carotid arteries; 2 and 2', right and left aortic arch; 4 and 4', pulmonary arteries. The right aortic arch, together with the tiny branch. *c*. form the descending aorta. (After Boas.)

arise from the mandibular arteries. There is, however, an external and internal **carotid artery** supplying the head and brain coming from each half of this first arch (Fig. 448). As various changes take place, however, the relation of the carotids makes them appear as though they arose from the first functional arch.

In the cyclostomes and fishes the various arches do not undergo much, if any, modification. Whatever modification does occur depends upon changes in the gills.

In all land vertebrates, and many of the fishes, the first arch on both sides disappears at the point where the external carotid artery begins.

When the spiracular gill is reduced, the second pair of arches is partially or completely lost in the adult.

The third pair persists. The blood for the **internal carotids** flows through these. In fishes, gymnophiona, and a few urodeles, the blood for the radices aortae also flows through the third pair. In all four-footed animals the radix disappears between the third and fourth arches so that it leaves the third arch purely carotid. In such a case that part of the ventral aorta between the third and fourth arches carries the carotid blood along and hence is known as a common carotid artery (Fig. 448, I, B), which usually then divides into a right and left branch.

The fourth pair are the **systemic trunks,** in all four-footed animals, and carry blood from the ventral to the dorsal aortae.

The fifth has become smaller, disappearing in nearly all animals except lizards and urodeles. In reptiles the left side of the fourth arch becomes separated from the rest of the ventral aorta, having its own trunk connected with the right side of the partially-divided ventricle, thus carrying a mixture of arterial and venous blood. The blood from the left fourth arch on the dorsal side is largely distributed to the digestive tract. The right side of the arch and the carotids are connected with the left side of the heart and are consequently purely arterial, the arch itself forming the main trunk connecting the heart with the dorsal aorta. In birds the radix on the left side of the adult disappears caudad to where the subclavian artery begins, so that this arch supplies blood only to the left arm. The right arch is purely aortic in character. **In the mammals this is entirely reversed, the right arch being subclavian, the left supplying the dorsal aorta and the subclavian of that side.**

The bird in its embryonic growth (as exemplified by the chick embryo) turns upon its left side in about 80 per cent of all cases, and the right arch persists, while in mammals, the embryo usually turns upon its right side and the left arch persists.

When lungs are developed, whether that be in the lung fishes or any of the higher forms of animals, a pair of **pulmonary arteries** develop from the sixth pair of arches on the ventral side of the pharynx. These arteries grow caudad into the lungs. That part of the arch dorsal to these newly formed pulmonary arteries becomes reduced to a small vessel known as the **ductus arteriosus** or the **duct of Botallus** (Fig. 345, C, d, b) in some of the urodeles. In some of the higher vertebrates one occasionally finds a vestige of this persisting also, otherwise it entirely disappears.

The ductus Botalli is quite important in the embryonic circulation of amniotes, because the greater part of the blood goes through it to reach the dorsal aorta during the time the allantois is the organ of respiration, while only enough blood goes through the pulmonary artery to nourish the lung. The duct closes with the first inspiration of air, while all blood passing into the last arch goes to the lung.

In the lung fishes and amphibia where there is but a single ventricle in the heart, the pulmonary arteries are connected with the ventral aorta just as are the other aortic arches. In higher forms, however, such as the amniotes, where there is either a partial or complete division of the

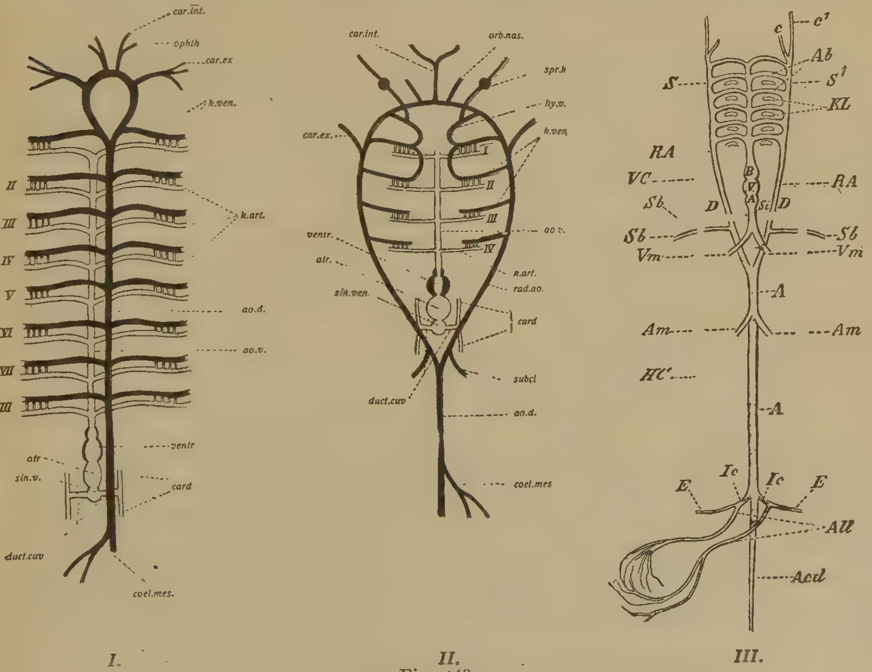


Fig. 449.

Schematic diagrams of circulatory systems in *I*, *Petromyzon*, *II*, *Teleosts*, *III*, in the higher vertebrates. I to VIII, gill arches; *A*, dorsal aorta; *A*, atrium; *Ab*, gill veins; *Acd*, caudal artery; *All*, allantoic artery; *Am*, omphalo-mesenteric artery; *RA*, and *rad.ao.*, Aortic radices (roots of the aorta); *S*. S^1, two branches *card.*, anterior and posterior cardinal veins; *car.ex.*, *c*, and *car.int.*, *c'* external and internal carotid arteries; *coel.mes.*, coeliaco-mesenteric artery; *duct.cuv.*, and *D*, duct of Cuvier; *E*, external iliac artery; *HC*, posterior cardinal vein; *Ic*, common iliac artery; *hy.v.*, gill veins of the hyoid arch; *k.art.*, gill arteries; *k.ven.*, gill veins; *KL.*, gill clefts; *ophth*, ophthalmic artery; *orb.nas.*, orbito-nasal artery; *RA*, and *rad.ao.*, Aortic radices (roots of the aorta); *S*. S^1, two branches of the gill veins which pass into the aortic radices; *Sb*, *Sb*, and *subl.*, subclavian artery; Sb^1, subclavian vein; *si*, and *sin.ven.*, sinus venosus; *spr.k.*, spiracle gill; *v*, and *ventr.*, ventricle; *VC*, anterior cardinal vein; *Vm*, omphalo-mesenteric vein. (From Schimkewitsch, I, after Vogt, Jung and Bridge; II, Parker, III, Wiedersheim.)

ventricle into two portions, the **conus arteriosus** and the ventral aorta are divided so that those portions which are derived from the sixth arch are connected with the right side of the heart, while the rest of the ventral aorta, with the exception already noticed in the reptiles, receives its blood from the left side of the heart.

It is necessary to study the figures very carefully in order to see how, already in the vertebrates such as the elasmobranchs, there is a differentiation of the fifth and sixth arches from the rest of the series. It will be remembered that the fifth arch is almost completely obliterated in vertebrates possessing lungs, and that the sixth is completely separated from the rest.

The dorsal aorta comes into existence by the fusion of two primitive vessels running caudad. These lie dorsal to the mesentery and run almost parallel to the notochord to the very end of the body. This fusion varies; it may extend as far forward as the aortic arch. It will be remembered that the portions which would normally be called the dorsal aortae, when these segment, or when there is a division between the various arches, are called **radices aortae.** Sometimes the dorsal aorta extends still farther forward than the last aortic arch and involves the whole of the radices, so that the dorsal aorta in this case extends to the first arch.

As many students studying comparative anatomy are preparing for medicine, dentistry, and other professions, it is necessary to call attention here to the fact that the names in human anatomy are somewhat different from those adopted in books on Comparative Anatomy. In the study of human anatomy that part of the ventral aorta which persists is called the **ascending aorta**; that part of the fourth arch which continues in existence is known as the **arch of the aorta**; and the rest of the dorsal aorta running downward toward the feet is called the **descending aorta.** This, in turn, is divided into one portion (passing into the thorax) known as the **thoracic aorta,** while from the diaphragm downward (as it passes into the abdominal cavity) it is known as the **abdominal aorta.** The last two names are thus only convenient terms to show the location of the descending aorta.

ARTERIES OF THE DORSAL AORTA

These are known as **visceral (splanchnic),** and **somatic.** As these terms are already familiar to the student it is merely necessary here to state that the visceral arteries run through the mesenteries where the double layers of serosa are found, and furnish the blood supply of the digestive tract. Many of the blood vessels are in a primitive condition though they are not metameric. Usually, especially in vertebrates, these smaller vessels become united into larger trunks. The principal ones are as follows:

VISCERAL ARTERIES (Fig. 444)

Coeliac Artery:

Origin, Radix or adjacent dorsal aorta.
Branches, Gastric, splenic, hepatic.

Superior Mesenteric Artery (running to cephalic portion of intestines). Develops with the omphalomesenteric.

Inferior Mesenteric Artery (to caudal portion of intestine). (Not always present, while other mesenteric arteries appear.)

Coeliac Axis—is the name applied if the superior mesenteric fuses with the coeliac artery.

Hypogastric Arteries:

Originally connect dorsal aorta with subintestinal vein near anus, later supplying rectum.

In animals higher than vertebrates a urinary bladder grows from the rectal region and this is supplied by hypogastric branches called **vesical arteries.**

In amniotes, where the distal end of the bladder becomes the allantois, parts of the vesical arteries become **allantoic arteries** or **umbilical arteries,** because they pass through the umbilicus. With the disappearance of the allantois these arteries degenerate, leaving only the rectal and vesical branches of the hypogastric trunk.

Caudal Aorta:

That portion of the dorsal aorta caudad to the hypogastric arteries.

SOMATIC ARTERIES

Distributed to body wall and its derivatives. (Contrary to the visceral arteries, the somatic arteries are arranged metamerically.)

Intercostal Arteries (Fig. 444):

One pair develop between each pair of myotomes, beginning at the radices and the dorsal aorta. As the aortic arches disappear and change, the intercostals become connected close to their origin by a pair of vertebral arteries running through the openings in the transverse processes of the vertebrae. The intercostals have different names, depending on their location, as **thoracic, lumbar, sacal,** etc.

Vertebral Arteries:

In both man and other vertebrates the vertebral arteries pass in a cephalad direction toward the ventral side of the medulla oblongata where the right and left arteries unite to form one trunk called the **basilar artery.** This runs straight forward underneath the brain. Two branches of the vertebrals extend caudad from points just before where the two vertebrals unite.

Circle of Willis:

Just before the basilar artery reaches the **hypophysis** (pituitary body) it divides, so that one-half of the basilar passes on each side of the hypophysis. The **internal carotid artery** meets this divided basilar on each side and the trunks thus formed meet near the **optic chiasma** forming a complete **arterial ring** called the **circle of Willis.** It will be noticed that the brain has thus a supply of arterial blood from both ventral and dorsal regions, making it less likely to suffer from anything that might impede the circulation in any one part.

Subclavian Arteries:

As the limbs grow out, a segmental artery for each somite concerned in the appendages, extends into the member. These arteries become connected with each other distally as well as with the veins of the limb by a network of small vessels. The parts of these main trunks and the connecting network enlarge while other portions atrophy. There are numerous variations in the blood supply of the limbs. This explains the shiftings of the subclavian artery shown in Figure 448.

The subclavian has the following names applied to different portions:

Axillary—that part lying in the axilla.

Brachial—that part lying in the upper arm.

Radial and Ulnar—the ones lying adjacent to the bones of these names.

Epigastric Arteries:

The development of the arteries of the hind leg is somewhat complex. There is the same formation of a capillary network as with the fore-limb. Two of the arteries become prominent. The **epigastric artery** lies forward. It descends from the aorta to the ventral side of the body and forward, supplying the lower portion of the myotomes. It becomes connected with the epigastric veins at first, although later these may anastomose with the hinder ends of the cutaneous arteries. When the hind limb grows out, the **external iliac** or **femoral artery** (a branch of the epigastric), is sent into its anterior side. As the leg increases in size this sometimes surpasses the parent epigastric in size, so that the latter appears as a mere side branch.

Sciatic Arteries:

The **sciatic** or **ischiadic arteries** descend into the posterior side of the leg, the name changing at the angle of the knee to **popliteal artery.** Farther down this artery divides into **peroneal** and **anterior** and **posterior tibial arteries.** The peroneal supplies the calf of the leg and the others continue into the foot.

The arrangement of vessels here outlined is characteristic of the lower tetrapoda where the femoral artery is small. It is likewise characteristic of the embryos of mammals. In the latter, however, before birth, the femoral artery grows down to join the popliteal, and so becomes the chief supply of the limb. These trunks and the hypogastric do not always remain distinct. They often fuse in different ways at the base. Epigastric and hypogastric arteries are distinct in many reptiles and in birds, but in other vertebrates they fuse to form the **common iliac artery,** so called because the proximal portion of the femoral is often called the **external,** and the hypogastric the **internal iliac artery.** The sciatic, likewise, may remain distinct, or it may fuse with the others at the base, and then its independent portion will appear as a branch of the common iliac artery.

A **cutaneous artery** arises from either the subclavian or the pulmonary artery of either side (both conditions occur in the amphibia) to run backward in the skin of the trunk. It may extend back and unite with the epigastric artery. If, as in the amphibia, these arise from the pulmonary artery, they contain venous blood and the skin acts as a subsidiary respiratory organ.

Renal Arteries:

Renal arteries are paired and show metamerism in the primitive state, details of which are given in the description of the organs they supply. It is well to note that metamerism is well shown in these arteries going to the pronephros and the mesonephros, while in the true kidney—the metanephros—only a single pair of renal arteries furnishes the blood supply.

Genital Arteries:

These, like the renal arteries, are paired and metameric in the primitive state and are called

Spermatic in the male.
Ovarian in the female.

These are more numerous in lower animal forms than in higher.

THE VEINS

Omphalomesenteric Veins:

It will be remembered that the heart is developed in the pericardial cavity. Caudad to the heart region the liver begins developing and thus prevents the lateral plates from coming together on the ventral side as they did in the case of the heart. The lateral plates, however, become grooved, and each one forms a tube, so that there are two vessels, called the **omphalomesenteric veins** extending caudad from the heart, passing around the liver where they meet with the extensions of the omphalomesenteric arteries already described (Fig. 277).

Subintestinal Veins:

Caudad to this connection a pair of **subintestinal veins** (Fig. 450) run toward the tail end on the ventral side of the digestive canal. These fuse together into a medial tube just behind the anal opening, which ex-

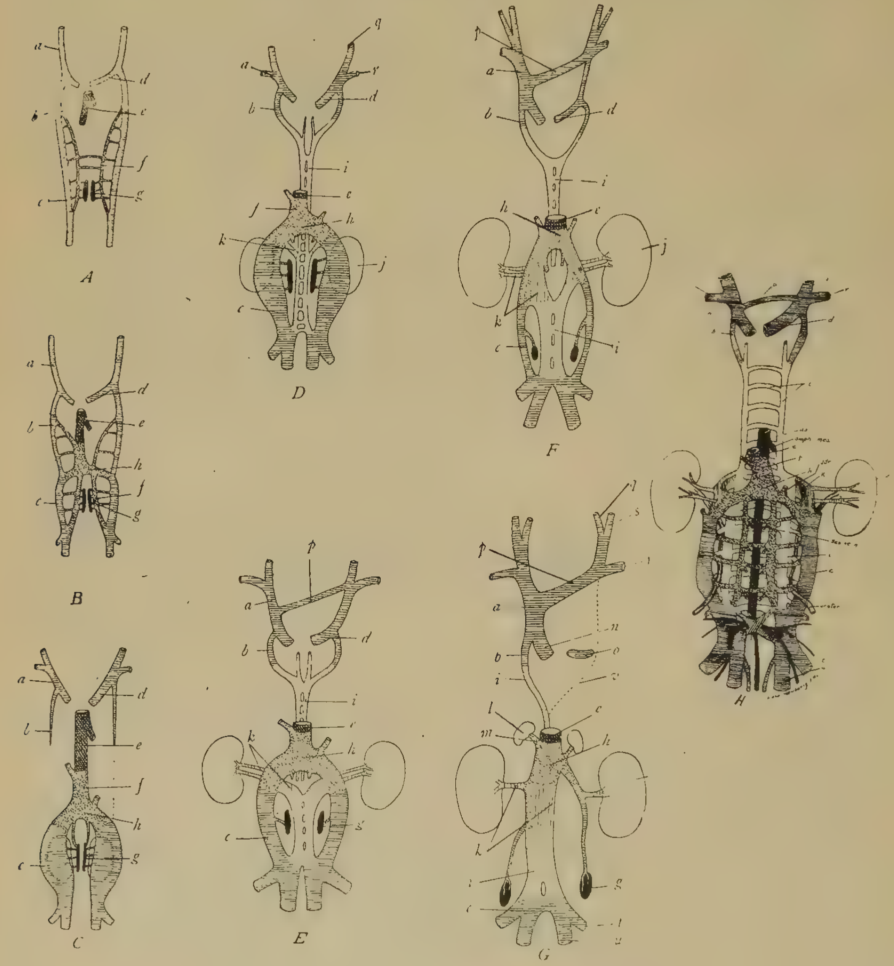


Fig. 450.

Diagrams to show the development of the postcaval vein in the cat. The *cardinal* system of veins is cross-hatched, the *subcardinal* veins closely stippled, the *hepatic* veins are indicated by cross, vertical, and oblique hatching combined, the *supracardinal* veins by open stippling, and the *renal collar* by vertical hatching. *A*, early stage, showing the anterior and posterior cardinal veins, *a*, *b*, *c*, the common cardinal vein *d*, the subcardinal veins *f*, and the outgrowth *e* from the hepatic veins of the liver. *B*, next stage, showing the union of the hepatic outgrowth *e* with the subcardinal veins *f*, to form the proximal part of the postcaval vein; the two subcardinals have united with each other at *h*. *C*, the anterior part of the posterior cardinal vein *b* has separated from the posterior part *c*, *c* now being the renal portal vein; the postcaval vein is seen to be formed of the hepatic vein *e*, the right subcardinal *f*, and to be united by means of the two subcardinals below *h* with the renal portals *c*.

tends to the end of the tail. This fused portion is known as the **caudal vein.** In the cyclostomes this connection persists. It disappears in other vertebrates.

The left Omphalomesenteric vein, which passes along the left side of the liver, continues to carry blood from the caudal or posterior part of the body to the heart, while the right disappears with the exception of the small portion between the sinus venosus and the liver.

The Portal System:

It will be remembered that the liver develops from a simple sac into a compound tubular glandular structure. The left omphalomesenteric breaks up into a great mass of capillary-like tubules or **sinusoids,** which pass among the tubules of the liver and end by reconnecting at the cephalic end of the liver. As the liver increases in complexity so do these sinusoids. The left omphalomesenteric is consequently quite important during this period and it is known as the **ductus venosus (Arantii),** (Fig. 451). A little later, however, this importance is lost by a part of the omphalomesenteric becoming the **portal vein,** which brings all the blood from the posterior regions of the body to the liver, sending it through the tiny sinusoids. The ends between the heart and the liver, formerly called the **ductus venosus,** now become the **hepatic veins.** It is in and through the hepatic veins that the collected blood from the liver sinusoids is sent to the heart.

When a vein breaks up into capillaries of this kind, as in the liver and kidneys, and its contents are again gathered in a vein, it is called a **portal system.** That of the liver is the **Hepatic portal,** while that of the kidney the **Renal portal system.**

In elasmobranchs and sauropsida, which produce eggs with large

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D, the supracardinal system of veins *i*, represented by open stippling, has appeared and has united anteriorly with the anterior parts of the posterior cardinals *b*, medially with the subcardinals by an anastomosis *k*, named the renal collar, and posteriorly with the renal portals *c*.

E, union of the two anterior cardinals by a cross-connection *p*, and development of the renal veins from the renal collar *k;* the supracardinal veins have separated into anterior parts connected with the posterior cardinals *b* and posterior parts connected with the subcardinals and renal portals *c*.

F, continuation of *E*.

G, adult stage; the left anterior cardinal joins the right by means of the cross-vein *p* which is the left innominate vein; the common stem *a*, which is the right anterior cardinal, enters the heart by way of *n*, which is the right common cardinal vein; the left common cardinal vein persists as the coronary sinus *o;* the right anterior parts of the posterior cardinal vein and supracardinal form the azygos vein, *b* and *i*, while on the left side these are obliterated at *v;* the postcaval vein is now complete and is seen to be composed of the hepatic vein *e*, the right subcardinal, the anastomosis between the two subcardinals at *h*, the right renal collar *k*, the posterior part of the supracardinal vein *i*, and the posterior parts of the renal portals (posterior cardinals) *c*: the left subcardinal and posterior cardinal contribute to the vein of the left gonad, hence the asymmetrical arrangement of the genital veins in mammals.

H, composite diagram of the veins of a cat. *a*, anterior cardinal; *b*, anterior part of the posterior cardinal; *c*, posterior part of posterior cardinal or renal portal; *d*, common cardinal; *e*, hepatic portion of the postcaval (this is partly removed in Figs. *D-G*;) *f*, subcardinal; *g*, gonad; *h*, union between the two subcardinals; *i*, supracardinal; *j*, kidney (metanephros); *k*, renal collar or union between subcardinals and supracardinals; *l*, adrenal gland; *m*, vein to adrenal gland; *n*, base of the precaval vein or right common cardinal; *o*, coronary sinus or left common cardinal; *omph.mes.*, omphalomesenteric artery; *p*, left innominate or connection between the two anterior cardinals; *q*. internal jugular; *r*, subclavian; *s*, external jugular; *t*, external iliac; *u*, internal iliac. (Partly from Hyman after Huntington and McClure in *Anatomical Record*, Vol. XX.)

yolk, the presence of a large food supply exercises a modifying influence on these ventral veins. A pair of large **vitelline veins** runs out into the yolk sac, over the yolk, from the junction of the omphalomesenteric and the subintestinal veins to play a large part in the transfer of material to the growing embryo (Fig. 284). The distal parts of these veins follow the margin of the yolk sac, forming a tube (**sinus terminalis**), into which smaller veins empty. Blood is brought to the yolk by the omphalo-mesenteric arteries. These arteries are also distributed to the yolk sac and divide up distally into a network of capillaries which connect distally with the vitelline veins. The blood is carried by these vitelline veins to the liver and through the portal circulation to the heart. In the mammals a similar vitelline circulation is developed, but here the yolk sac contains no yolk, and so is of minor importance and soon lost.

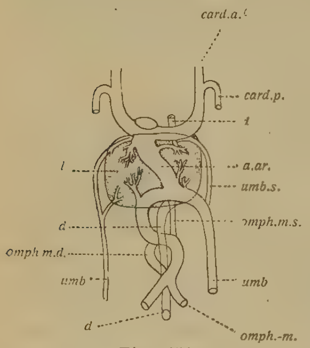

Fig. 451.

Diagram showing development of the mammalian hepatic portal system. The omphalo-mesenteric and the umbilical veins are reduced. *card.a.* and *card.p.*, anterior and posterior cardinals; *d*, intestine; *d.ar.*, ductus venosus (*Arantii*): *l*, liver; *omph.m.d.* and *omph.m.s.*, right and left omphalo-mesenteric veins; *umb.d.* and *umb.s.*, right and left umbilical veins. (After Hochstetter.)

In amniotes there is an outgrowth, the allantois, which arises as a diverticulum from the hinder end of the alimentary canal. This increases in extent by growing downward and carrying the ventral body wall before it. **Allantoic arteries** (branches of the hypogastric arteries) extend into it and are connected by capillaries with **umbilical veins** which arise from the subintestinal vein behind the vitelline veins. This forms an **allantoic circulation** which is both respiratory and nutritive in character. In the reptiles, both of the umbilical veins persist through foetal life, while in birds and mammals, one aborts, leaving the other as the efferent vessel of the allantois. With the end of foetal life (at hatching or at birth) both the vitelline and the allantoic circulations disappear, leaving only inconspicuous rudiments.

Anterior Cardinal Veins (Superior Jugular or Jugular):

(The **inferior jugulars** are found only in fishes and salamanders, where they drain lateral and ventral branchial regions.) The superior jugular vein lies dorsal to the gill-clefts and returns blood from the dorsal regions of the head.

Post Cardinal Veins (Figs. 450, 456).

These are very clearly related in development with the excretory system and lie dorsal to the coelom and dorsal to the nephridial arteries. Nearly all of the thoracic portion of the post cardinal veins soon disappears in the higher forms, while a **supra cardinal system** develops, as shown in the figures. This supra cardinal system in turn disappears with the exception of a posterior portion which takes part in the forming of the post cava, and the right anterior portion which connects with the remnant of the post cardinal to become the **azygous** vein. If the anterior left side persists also, this is known as the **hemiazygous.**

In the lower vertebrates they retain their function of draining the excretory system.

Cuvierian Ducts:

These are formed by the meeting of the anterior cardinal and the post-cardinal vein on each side to form short tubes for the emptying of the cardinal veins into the sinus venosus.

Subcardinal Veins:

These are closely associated with the post-cardinals.

As the mesonephroi in their development reach the hinder end of the coelom, the caudal vein loses its primitive connection with the subintestinal vein and becomes connected with a pair of vessels, the **subcardinal veins,** which develop in a ventral-medial position to the two mesonephroi. The blood from the tail now goes through the subcardinals and from them into the excretory organs, passing through a system of capillaries to be gathered again in the postcardinals and by them to be returned to the heart. Here, then, there is another portal system, the **first renal-portal system,** which may be modified later.

Subclavian Veins:

One of these drains each forelimb. It originally empties into the post-cardinal but later may empty into the Cuvierian duct or jugular vein.

Common Iliac Vein:

This drains the hind limb and empties into the epigastric **(lateral abdominal)** vein, which in turn empties into the post-cardinal or duct of Cuvier.

While this is the condition in some elasmobranchs, in the reptiles and amphibia the common iliac sends part of its blood as above, and part through the post-cardinal of its own side, so that blood from the hind limbs has two routes to the heart.

Anterior Abdominal Vein:

In amphibia and some reptiles the two epigastric veins fuse in the midline to form an **anterior abdominal vein,** which passes through the remains of the ventral mesentery **(ligamentum teres),** to the liver and forward.

In one mammal, **Echidna** alone, has such an anterior abdominal vein been found.

The vessels of the appendages are but slightly developed in **fishes.** There is a subclavian vein which enters the Cuvierian duct, and sometimes a **branchial vein** which may empty into the sinus venosus. In the **amphibia** a **cutaneous magnus vein** comes from the skin of the trunk which may enter the subclavian. In all **tetrapoda,** the subclavian, after it leaves the limb, receives a superficial **cephalic** and an **axillary vein.** The latter, however, changes its name in the appendage to the **brachial vein.** The common iliac vein is formed in the limb by a union of the femoral and sciatic (ischiadic) veins, as well as the **hypogastric** (internal iliac) vein.

In all classes above fishes, such as dipnoi, amphibia, and amniotes, a new vein, the **postcava (vena cava inferior)** arises in part from scattered spaces and in part as a diverticulum of the sinus venosus and the hepatic veins. It grows backward, dorsal to the liver, until it meets and fuses with the right subcardinal vein, a portion of which now forms a new trunk to carry blood from the posterior part of the body to the heart.

The following changes are introduced in the embryonic renal portal circulation whenever a postcaval vein develops. The subcardinals no longer connect with the caudal vein but are connected with each other by transverse vessels **(interrenal veins).** Portions of the postcardinals grow backward to connect with the caudal vein. These posterior parts of the postcardinals then become the **advehent veins** (Fig. 452) of a sec-

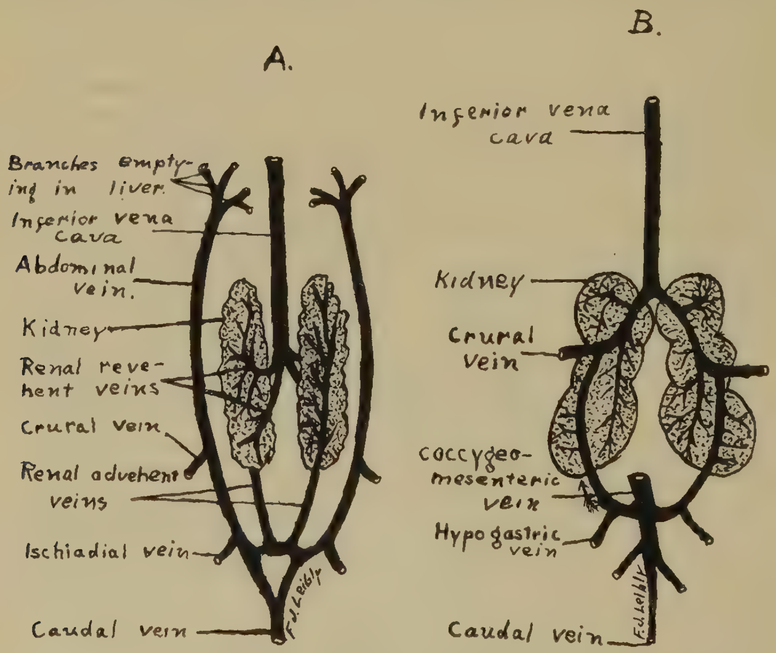

Fig. 452.

Diagram of Renal Portal System in *A*, Alligator, and *B*, Bird. (After Gegenbaur.)

ond renal portal system. They bring blood from the tail and hind limbs to the excretory organs (mesonephroi). The subcardinals of both sides usually fuse in the middle line. The fusion is initiated by the appearance of the interrenal veins, which now act as **revehent vessels** to carry blood from the excretory organs to the postcava and to the anterior portion of the postcardinals which have joined the anterior ends of the subcardinals. In mammals there is also a change in the postcardinals and in the renal portal system.

In the lung fish **Ceratodus** there are some differences from the above account. Here the cephalic portion of the right postcardinal loses its connection with the vessels behind, and acts as a **vertebral** vein, taking the blood from the intercostal veins of that side back of the heart. The caudal and the subcardinals form a continuous trunk, while the revehent vessels form side branches. The caval portions of the postcardinals grow back into the tail as paired vessels, forming no connection with the caudal vein. In **Protopterus** there is no vertebral vein and the subcardinals are not fused behind, while the advehent veins are connected with the caudal.

Pulmonary Veins:

There may be various pairs of these. They carry blood from the lungs to the left auricle of the heart. They never empty into the sinus venosus.

THE LYMPHATIC SYSTEM

In addition to the arterial and venous divisions of the circulatory system, all craniates develop **lymph-vessels** or **lymphatics.**

These consist of a network of lymph capillaries which are interwoven with, but independent of, the blood-capillaries. The lymphatic system is not closed like the blood-vascular system, for there are not only definite lymph vessels, but there are large open spaces—the **lymph-sinuses**. Then, too, there are connections by little apertures, called **stomata,** between the lymphatics and the coelom.

Lymph sinuses are found beneath the skin, as in the frog, between muscles, in the mesenteries, in the walls of the alimentary tract, around the central nervous system, and in many other parts of the body.

The lymph (which is practically the liquid part of the blood which seeps through the blood vessel walls) is gathered in these sinuses and then passes into more or less definite lymph vessels which, in turn, open into the veins (Fig. 453).

Leukocytes are added to the plasma from the various lymphatic glands (Fig. 453), such as the tonsils, thymus, and spleen.

In the lower craniates, such as the frog, lymph-hearts occur (Fig. 347). These are muscular dilations found in the course of certain vessels.

The lymph glands (Fig. 453) are made up of a network of connective tissue in which the lymph leukocytes **(lymphocytes)** are formed.

The function of lymph glands, therefore, seems to be that of destroying foreign bodies and to add white blood corpuscles to the general circulation. The lymph itself bathes all the cells of the body. There are no red blood corpuscles in lymph.

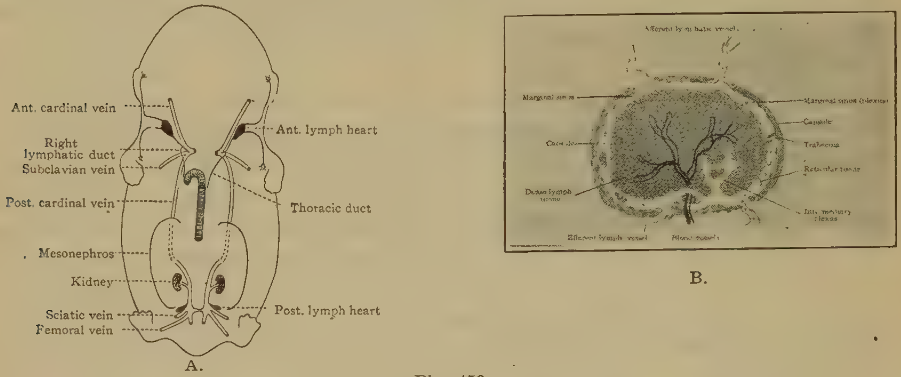

Fig. 453.

A, Diagram showing arrangement of lymphatic vessels in a 20 mm. pig embryo. (After Sabin.)
B, Diagram illustrating a stage in the development of a lymph gland. (After Stöhr.)

The lymphatics of the intestine are called **lacteals** and perform the important function of absorbing fats from the ingested food. These lacteals combine with the lymphatic vessels from the hind limbs and body to form a receptacle known as the **receptaculum chyli,** from which a tube **(thoracic duct)** passes cephalad to open into one of the large veins of the precaval system by a valvular opening. The thoracic duct is often double.

In mammals the lymphatic system ramifies throughout all portions of the body. The lymphatic system is too delicate to be worked out by the ordinary laboratory dissection.

SUMMARY OF THE CIRCULATORY SYSTEM

AMPHIOXUS (Fig. 444)

The blood vessels are all of one kind, but due to various homologies with the more complex vessels of higher animal forms, some are called **arteries** and others **veins.**

The circulatory system consists of a ventral pulsating vessel, without a specialized heart enlargement. This pulsating vessel pumps the colorless blood forward and through the branchial arches to be aerated. The blood then collects in paired dorsal aortae which unite back of the pharynx into a single dorsal aorta. Branches are sent from this dorsal aorta to the walls of the intestine where they break up into capillaries.

The blood is collected from these capillaries into a median longitudinal **sub-intestinal vein,** through which the blood flows forward to pass into the **hepatic portal vein** at the origin of the liver. This portal vein breaks up into capillaries within the liver and is then collected in the **hepatic vein** which extends along the dorsal portion of the digestive gland, where it turns downward and forward to join the caudal end of the ventral pulsating vessel.

The vascular system of **Amphioxus,** therefore, consists primarily of (I) a dorsal vessel represented by the paired and unpaired dorsal aortae, (II) a ventral vessel represented by the subintestinal vein and the ventral aorta, and (III) commissural vessels represented by the afferent and efferent branchial arteries and the intestinal capillaries. This is quite similar to the circulation in the earthworm except for two important differences. The blood in the ventral vessel of **Amphioxus** travels forward, that in the dorsal vessel backward—just the reverse of what occurs in the earthworm, while the ventral vessel is broken up into two parts, by the interposition in its course of the capillaries of the liver, so that all the blood from the intestine has to pass through the liver before reaching the ventral aorta. This passage of the intestinal blood through the vessels of the liver constitutes what is called the **hepatic portal system,** which is characteristic of all vertebrates.

FISHES

The circulation in fishes corresponds quite closely in the main to that of the chick's embryonic circulation. It is built about the gill system. The blood is pumped forward from the ventral heart through the gills, and is then, as arterial blood, carried backward in the dorsal aorta. This scheme of circulation wherever found is interpreted as **primarily aquatic.**

The heart consists of four chambers: (a) **sinus venosus,** (b) **auricle,** (c) **ventricle,** and (d) **conus arteriosus,** through which blood passes in the order given. The sinus and auricle lie dorsal to the ventricle.

In the lampreys there is no portal system.

In the dogfish (Figs. 446, 449, 454), the circulation is laid out in accord with the branchial system. The blood brought to the heart by the venae cavae is pumped forward through a common ventral aorta which divides into five pairs of **afferent branchial arteries,** each of which carries blood to one set of branchiae. A corresponding **efferent branchial vessel** picks up the aerated blood from the branchiae and carries it to a dorsal aorta, through which it is distributed to all parts of the body, both anteriorly and posteriorly. The **general systemic, hepatic-portal,** and **renal-portal systems** return the blood to the heart along dorsal vessels called **anterior and posterior cardinal veins.**

The fish-type of circulation is built primarily along lines laid down by the branchial respiration and the heart pumps blood forward and

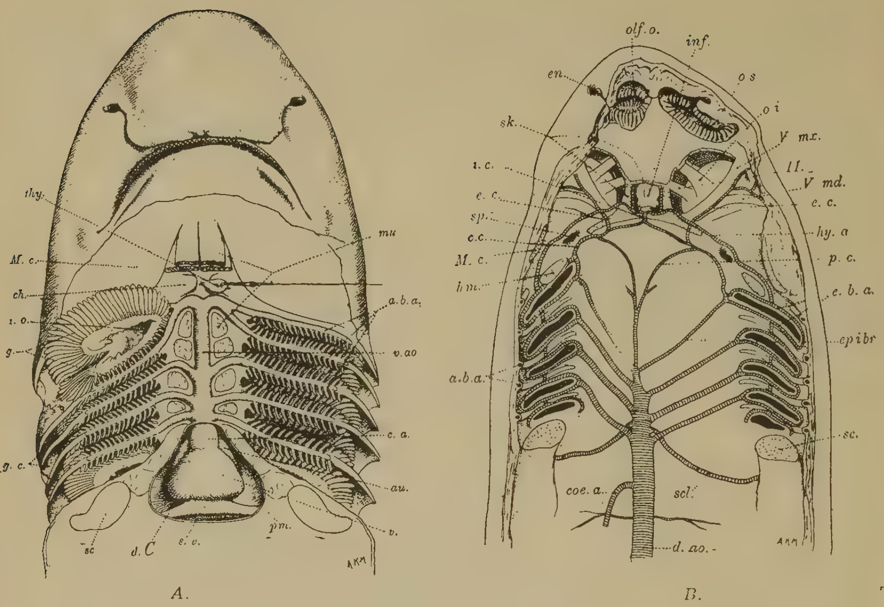

Fig. 454.

A, The forepart of the body of a dogfish, dissected to show the heart and ventral arterial system. *a.b.a.*, Afferent branchial arteries; *au.*, auricle; *c.a.*, conus arteriosus; *ch*, ceratohyal cartilage; *d.C.*, ductus Cuvieri; *g.*, gills; *g.c.*, gill clefts; *i.o.*, internal opening of the first gill cleft; *M.c.*, Meckel's cartilage; *mu.* muscles from coracoid region of shoulder girdle to various parts of visceral skeleton; *pm.*, pericardium; *s.v.*, sinus venosus; *sc.*, scapula; *thy.*, thyroid gland (displaced); *v.*, ventricle; *v.ao.*, ventral aorta.

B, The forepart of a dogfish, dissected from the ventral side, to show the dorsal arterial system, the olfactory organs, and certain structures in the orbits. The middle part of the floor of the mouth has been removed. *a.b.a.*, Afferent branchial arteries; *c.c.*, common carotid artery; *coe.a.*, cœliac artery; *d.ao.*, dorsal arota; *e.b.a.*, efferent branchial arteries; *e.c.*, external carotid; *en.*, nostril; *epibr.*, epibranchial artery; *hm.*, hyomandibular cartilage; *hy.a.*, hyoidean artery; *i.c.*, internal carotid arteries; *inf.*, infundibulum; *M.c.*, Meckel's cartilage in lower jaw; *o.i.*, inferior oblique muscle; *o.s.*, superior oblique muscle; *olf.o.*, olfactory organ; *p.c.*, posterior carotid artery; *sc.*, scapula; *scl.*, subclavian artery; *sk.*, skull; *sp.*, spiracle; *V.md.*, *V.mx.*, mandibular and maxillary branches of fifth nerve; *II.*, optic nerve. (After Borradaile.)

through the branchial arches. This involves as many pairs of branchial arches as there are paired functional afferent vessels carrying blood to the gills, and efferent vessels carrying the oxygenated blood from the gills to the dorsal aorta.

AMPHIBIA (Figs. 446, 456)

The principal changes in the amphibian circulation are concerned with the branchial arches. These are remodeled to become blood vessels that can function in an air-breathing animal. The **branchial vessels** of lobe-finned ganoids and of amphibia in the larval stage consist of four pairs; known from the region in which they develop as the **third,** fourth, fifth and sixth. The **third** pair becomes the **carotid arteries that** supply the head; the **fourth** becomes the **systemic arches** that supply most of the body; the **fifth disappears,** and the **sixth** becomes mainly **the**

pulmonary arches. It is of interest to note that in all lung-breathing fishes, the lungs are supplied from the branch of the sixth branchial arch. In most amphibia, a branch of the **sixth** arch becomes **cutaneous,** for the skin respiration is almost as important as the pulmonary. The heart is carried back into the trunk and consists of a sinus venosus, right and left auricle, ventricle, and conus arteriosus. The auricle has divided into a systemic half and a pulmonary half which lie in front of the ventricle. The single ventricle receives both arterial and venous blood, but there is very little mixture of the two.

The postcava is well developed and the lateral abdominal veins (also called epigastric) unite to form an anterior abdominal vein. This latter vein permits the return of blood from the hind legs to the heart either through the anterior abdominal and the hepatic portal system or the renal portal system and the postcava.

REPTILIA (Figs. 447, 448, 452, 455)

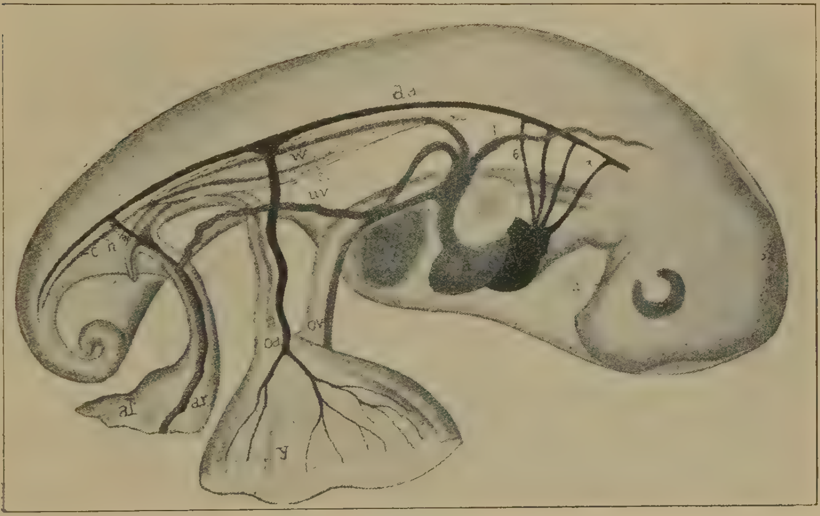

Fig. 455.

Embryonic circulation of a Snapping Turtle (Chelydra) to show the relations of allantois. *a*, right auricle; *al*, allantois; *av*, allantoic vessels; *c*, caudal vein; *da*, dorsal aorta; *h*, hypogastric artery; *j*, jugular, *l*, liver; *oa*, *ov*, omphalo-mesenteric artery and vein; *pc*, post-cardinal; *sc*, subcardinal vein; *uv*, umbilical vein; *w*, Wolffian body; *y*, yolk-sac; 3-6, aortic arches. (From Kingsley after Agassiz and Clarke.)

The heart is very broad laterally and consists of a sinus venosus (although only distinguishable in **Sphenodon** externally), two quite distinct auricles (the right receiving venous blood from the body, and the left aerated blood from the lungs), and a ventricle always more or less completely divided into right and left portions. (In the crocodile the partition is complete.)

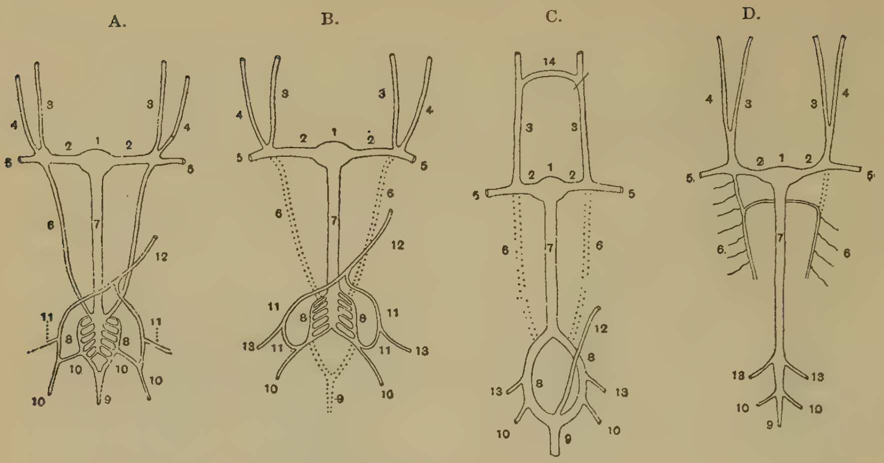

Fig. 456.

Diagrams to show arrangement of principal veins in A, *Urodele*, B, *Anura* and *Reptilia*, C, *Bird*, D, *Mammal*. 1, Sinus venosus, gradually disappearing in the higher forms; 2, Ductus Cuvieri (superior vena cava); 3, Internal jugular (anterior cardinal sinus or vein); 4, External jugular (sub-branchial); 5, Subclavian; 6, Posterior cardinal, front part (venae azygos and hemiazygos of higher forms); 7, Inferior vena cava; 8, Renal portal (hinder part of posterior cardinal); 9, Caudal; 10, Sciatic (internal iliac); 11, Femoral in *A*, Pelvic in *B*; 12, Anterior abdominal in *A* and *B*, coccygeomesenteric in *C*; 13, Femoral (external iliac) in *B*, *C*, and *D*; 14, Anastomosis of jugulars in *C*. (From Shipley and MacBride.)

The sinus venosus receives the venous blood from two precaval (really the Cuvierian duct) and one postcaval vein. The blood passes through the right auricle into the right half of the ventricle, after which it passes through the **pulmonary arteries to the lungs. From the lungs** it returns through the **pulmonary veins** to the left auricle and thence to the left ventricle. From here it is pumped out through the paired aortic arches to all parts of the body. There is both a renal and a hepatic portal system.

Often there is a foramen (of Panizza) connecting the right and left fourth aortic arches, so that blood can pass from one side to the other.

BIRDS (Figs. 444, 446, 447, 448, 452)

The heart is large and has two definite auricles, two ventricles, and no distinct sinus venosus. The right auricle receives the venous blood from the general body, while the left receives the aerated blood as it is returned from the lungs. The **right aortic arch** carries all of the arterial blood to the system. The renal-portal system is vestigial.

MAMMALIA

The mammals retain the **left aortic arch** and lose the right, while birds retain the right arch and lose the left. Modern reptiles show a tendency to reduce the left arch.

The valves between auricle and ventricle are tricuspid on the right side and bicuspid (mitral) on the left. In the monotremes, however, both valves have three cusps.

The pulmonary artery and aorta all have three-lobed semilunar valves.

In the monotremes the renal portal system is better developed than in other mammals although in all mammals it functions but for a short time and disappears with the degeneration of the mesonephroi (Wolffian bodies).

A part of the capillary system of the mesonephroi enlarge during the degenerative process to form a main trunk which connects the postcava with the caudal portions of the postcardinal veins. It is the postcardinals that drain the tail, iliacs, and metanephroi.

The left postcardinal largely disappears later with the exception of that portion which connects with the suprarenal and gonad of the left side. All the blood from the posterior part of the body is therefore returned through the right postcardinal and the postcava, whose origin appears to be at the union of the iliac veins.

In the turtle the postcaval vein unites with that part of the renal portal system which lies caudal to the kidneys and the renal portal system then passes out of existence.

This can be understood the better if it be remembered that the renal portal veins are the caudal portions of the posterior cardinal veins, and that the subcardinal veins (particularly the right subcardinal) form the postcaval vein which lies between the kidneys.

In mammals the postcaval vein is formed principally of the distal ends of the posterior cardinal veins, and of the right subcardinal, of the (vitelline) hepatic veins close to, and cephalad to, the liver, as well as of the hepatic veins which lie between the liver and the hind limbs. As the postcaval vein is made up of so many different sources, there are bound to be many variations in the adult state due to more or less persistent embryonic conditions.

The more anterior portion of the postcardinal veins loses its connection with the portion connecting with the excretory organs, and with the thoracic portion of the supracardinals, to become the **azygous** vein on the right side and the **hemiazygous** on the left. Either of these may disappear or, as in man, there may be a cross connection between these two veins. In such a case the anterior part of the hemiazygous is known as the **superior intercostal vein.**

The abdominal veins are quite important in foetal life as they bring blood from the placenta to the embryo.

In the higher vertebrates, including man, an **innominate** vein extends across from the carotid-subclavian trunk from one side to the other. All the blood is thus returned to the heart by means of the base of the right trunk, which is now called the **precava** or **vena cava anterior.**

The Cuvierian duct remains only as the **coronary sinus.**

CHAPTER LIV.

THE UROGENITAL SYSTEM.

As has already been noted, not only in the frog but in several of the type-forms studied, there is an intimate connection between the excretory and the reproductive systems. In fact this is so intimate that it is impossible to take up either subject without touching upon the other. For this reason it is customary to treat both under the head of the **Urogenital System.** The excretory organs consisting of the paired **kidneys,** or **nephridic organs and their ducts,** serve the purpose of casting out of the body the waste matter containing nitrogen, and occasionally other substances.

The **gonads** (ovaries or testes) are the reproductive glands. To any and all of these, accessory structures are frequently added. The nephridic organs proper have already been quite fully described in the frog, a review of which is essential to the understanding of that which follows.

It will be remembered that the kidneys are **parenchymatous glands,** being composed of a soft, more or less spongy tissue in which there is a profuse quantity of blood. The great quantity of blood is sent through the tiny venules which anastamose with the arterial capillaries in the **Malpighian corpuscles** (Fig. 16.)

Some of the typical parts which go to make up the kidneys of higher forms are lacking in certain groups of animals. In the amniotes, nephrostomes are never formed, although they do occur in most ichthyopsida. In the pronephros the Malpighian corpuscle is rudimentary or lacking at all stages, while there is no differentiation of convoluted tubules and Henle's loop.

Professor Kingsley's excellent account of the urogenital system is followed here.

Theoretically the function of the various parts of the nephridial tubules is in outline as follows: In the primitive condition the nitrogenous waste, is elaborated in the liver, collected in the coelom and, together with the coelomic fluid is passed outward through the nephrostomes and the tubules, which act merely as ducts. "Higher in the scale the parts become more differentiated and specialized. The renal corpuscles form a filtering apparatus by which water is passed from the blood-vessels of the glomerulus into the tubules near their beginning, and this serves to carry out the urea, uric acid, etc., secreted by the glandular portions of the walls of the tubules (convoluted tubules, ascending limb of Henle's loop)."

"All three nephridia arise from the mesomeric somites or from the Wolffian ridge which appears on either side of the median line where the mesomeres separate from the rest of the wall of the body cavity, the mesomeric cells furnishing the nephrogenous tissue from which the definitive organs develop."

"Three views are held as to their relations one to another. According to one they are parts of an originally continuous excretory organ (holonephros) which extended the length of the body cavity. This has become broken up into the separate parts which differ merely in time of development and function, with minor modifications in details. A second view is that they are three separate organs, while a third regards them as superimposed structures which occasionally overlap (birds, gymnophiona) and thus are not, strictly speaking, homologous but rather homodynamous. The first view has the most in its support, but for convenience the three structures are kept distinct."

It is of considerable value to trace the successive series of these excretory structures in the different types of animals. It will be remembered that in some of the forms studied, such as the earthworm, there was an excretory organ in practically every segment of the animal's body. It will be further remembered that insistence has constantly been laid upon the fact that the so-called higher animal forms have practically every structure that the lower forms possess, **plus something additional.** This is well exemplified in the study of the nephridic organs.

The nephridic organs of the amniotes pass through a three-fold development. The first excretory organs which grow, form the **pronephros** or **head-kidney,** the next succeeding being known as the **mesonephros** or **Wolffian body,** while the last to form, which becomes the **permanent kidney** of the higher forms, is called the **metanephros.**

While all three are closely related both in their development and their structure, there is a difference in their origin and in some of the details.

THE PRONEPHROS.

As its name implies, that is the first of the excretory organs to appear. A review of the embryology of the excretory system must be had at this point.

As the myotome is being formed from the epimere, the dorsal end of each mesomere closes. This forms a sac which opens into the coelom. Each of these is called a **nephrotome** and lies a little behind the head. It is from these nephrotomes that the pronephros is formed. The number of pronephridic organs varies from one in the teleosts, to a dozen or more in the caecilians. The usual number, however, in the higher forms is two. From the somatic walls of these nephrotomes there is an outgrowth toward the ectoderm. This forms slender pronephric tubules as in the amphibia, or solid cords which later have a lumen from within them as in elasmobranchs and amniotes. They thus all become tubules, the proximal ends of each communicating with the metacoele by way of the cavity in the nephrotome. The opening to the metacoele is called a **nephrostome,** and as already noted, there will be as many tubules and nephrostomes as there are somites. The distal ends of the nephrotomes grow outward until they reach just below the ectoderm when they bend toward the caudal end of the body. Here the more cephalic tubules fuse with those behind and it is at this meeting place of the tube that the **pronephric duct,** sometimes called the **archinephric duct,** grows backward immediately beneath the ectoderm. This backward growth continues until the caudal end of the metacoele has been reached. It is here that the pronephric duct fuses with the caudal end of the digestive tract and empties into the cloaca, as in the frog, where it meets with the ectoderm close to the anal opening. In either case an opening then breaks through so that the contents of the duct can be expelled.

The question is often asked as to whether the ducts thus formed are of mesothelial origin or whether the ectoderm contributes a share. From present evidence it is assumed that the ectoderm has no share in their formation.

"The pronephros is functional for a time in the embryos of some lower vertebrates; in other groups it is a rudimentary and transitory structure save for its participation in the **oviducts** and the **ostium tubae abdominale.** When functional, it takes the nitrogenous waste from the body cavity, while its filtering apparatus consists either of separate **glomeruli** (one for each tubule) or the glomeruli of the separate somites may run together, forming a glomus. These glomeruli or the glomus of the pronephros do not project into a Bowman's capsule, but lie immediately above the dorsal wall of the coelom, between the mesentery and the nephrostomes, pushing the epithelium before them. Later, as in the caecilians, they and the nephrostomes may be enclosed in a cavity cut off from the coelom, so that the whole resembles a renal corpuscle, but is different in origin. In either case the exuding fluid passes into the metacoele, from which it is drawn by the cilia of the nephrostomes and passed into the tubules.

"The blood is brought to the glomus or glomeruli by short segmental arteries arising from the dorsal aorta and, after passing through the capillaries, it is carried away by the postcardinal veins of the corresponding side to the heart, these veins keeping pace in their backward development with the development of the nephridial tubules."

In all vertebrate adults, with the possible exception of **Bdellostoma** (Fig. 366), the pronephros has been replaced by the mesonephros and later still in the amniotes by the metanephros. In the cyclostomes and a few teleosts the pronephros, however, persists.

THE MESONEPHROS.

The mesonephros, also called the **Wolffian body,** is formed by a series of mesonephric tubules which are developed after the pronephros and its ducts are completely formed. The mesonephric tubules grow out from the nephrotomes behind those which form the pronephros. The tubules extend toward each side of the animal until they meet and fuse with the pronephric duct. This duct is then the excretory canal for the mesonephros. The point of origin of the mesonephric tubules varies in different animals. Some lie dorsal to the pronephric tubules while two arise from the same nephrotome one above the other. In fish and amphibians the nephrostome consists of the opening of the nephrotome into the metacoele. As this opening, however, is closed in the amniotes, even before the tubules are formed, there are no nephrostomes, and consequently there is no connection between tubules and the peritoneal cavity.

"Segmental arteries grow out from the aorta to the splanchnic wall of each nephrotome, forming there a network of capillaries at a higher level than the pronephric glomeruli. The glomerulus thus formed presses the wall before it, while the rest of the nephrotome closes around it as a Bowman's capsule, the whole forming a Malpighian body (in some rodents the glomeruli are rudimentary or absent). In most ichthyopsida the Malpighian body is connected on one side with the metacoele by the nephrostome, and on the other with the mesonephric tubule.

"Thus at first the mesonephros is a metameric structure, extending over a much larger number of somites than does the pronephros and reaching nearly to the posterior limits of the metacoele. As the development of the embryo proceeds, the number of tubules, in all vertebrates except the myxinoids, increases by budding in a manner not readily described. These tubules unite with those first formed, so that the distal part of these become collecting tubules. Each of these secondary tubules forms its own Malpighian body and all of the tubules elongate, become convoluted and the mesonephros loses its primitive metameric character.

"At the same time changes are introduced into the mesonephric circulation. The veins emerging from the renal corpuscles extend out into the region of the tubules, each breaking up there into a second system of capillaries which envelop the tubules before returning the blood to the postcardinal vein. The subcardinal vein brings the blood from the caudal region (and usually from the hind limbs) to the Wolffian body and this is also returned via the postcardinals to the heart."

THE MESONEPHRIC DUCTS.

In those animals seemingly more primitive, such as the elasmobranchs and in some of the amphibia, the pronephric duct divides longitudinally from its most caudal end forward, almost to the cephalic end of the Wolffian body. This occurs at the time the mesonephros develops. There are thus two ducts formed one of which, called **Wolffian** or **Leydig's duct**, remains connected with the tubules of the mesonephros and forms its excretory canal, while the other called the **Müllerian duct** is also quite closely related to the pronephros, but forms the oviduct in the female. In the amniotes the pronephric duct does not divide but becomes the Wolffian duct, while the oviduct arises in another manner. This same thing holds true in many of the amphibians and in all of the teleosts.

THE METANEPHROS.

While the mesonephros functions in all vertebrate embryos and throughout the entire life of fish and amphibians as well as a short time after birth in the lizards and opposum, this organ becomes replaced in the adult of all amniotes by the two metanephridic organs which form the **true kidneys.** Each of this pair of kidneys takes its origin directly behind the mesonephros of the same side, while from the caudal end of the Wolffian duct close to its entrance into the cloaca a tube, the **ureter,** grows forward parallel to the parent duct, into the tissue caudal and dorsal to the mesonephros. It is supposed that this is more or less metameric, although all trace of such metamerism has disappeared, the kidneys not being segmented in any stage of their development. The cephalic end of the ureter has a varying number of branches, whose tips expand to form what is called a **primary renal vesicle.** Around each primary vesicle a group of cells develops, the aggregate of which grows into an "S" shaped tubule, one end of which connects with the primary renal vesicle, the other developing into a **glomerulus.** There are no nephrostomes. Still later these tubules multiply extensively, while the blood capillary system of the glomerulus increases also.

THE URINARY BLADDER.

This reservoir for urine, also called a **urocyst,** forms toward the caudal end of the excretory ducts. There are three kinds of urocysts.

1. A bladder arising by the **fusion of the caudal ends** of the Wolffian ducts plus a portion of the digestive tract. This is the **cloaca type.** The Wolffian ducts in this instance empty into the cloaca, the cloaca then opening to the exterior.

2. The usual urinary bladder formed by a **diverticulum from the dorsal wall** of the cloaca, cephalad to the openings of the Wolffian ducts. It is supposed however that this form may be homologous with the rectal gland of the elasmobranchs.

3. The **allantoic bladder** occurring in all higher forms as a **ventral diverticulum** from the cloaca. The entire outgrowth forms the bladder in the amphibia, while **in the amniotes only the proximal portion** becomes the bladder. The distal portion is used in the embryo as a **respiratory organ,** the **allantois.** The allantois is quite extensive, forming a part of the placenta in mammals. It is either absorbed or lost at or before the time of birth.

In the higher forms in which a bladder is present, the ureters open directly into it, the urine being conveyed to the exterior through the single tube, the **urethra,** while in amphibia the urine must first pass through the cloaca before entering the bladder, as the Wolffian ducts do not directly enter the urocyst. In many birds and reptiles there is no urinary bladder at all although these have an allantois during their embryonic development.

"There is great difficulty in comparing the excretory system of the vertebrates with anything known in the invertebrates. In general the nephridial tubules may be compared with those of the annelids. Both have nephrostomes opening into the coelom, and convoluted tubules enveloped in a network of capillary blood-vessels, but in the annelid each tubule opens separately to the exterior in the somite behind that in which the nephrostome lies, while in the vertebrate the series of tubules empty into a common duct. When it was thought that the ectoderm contributed to the pronephric duct, the homologies appeared easy. The duct was originally a groove on the outer surface into which the separate tubules opened. Then the groove was rolled into a tube which continued backward to the vicinity of the anus. By the downgrowth of the myotomes the duct became cut off from its primitive position and came to lie just outside the peritoneal lining. When, however, it is considered that in all probability the pronephric duct is formed solely from the mesoderm the homology falls to the ground and an explanation is still a desideratum."

THE REPRODUCTIVE ORGANS.

A detailed study of the embryological beginnings and development of the reproductive organs has already been covered in that part of this book devoted to embryology. After this has been reviewed it will be understood how the germ plasm is early set aside in the growing embryo from which the gonads develop . The gonads are not segmented notwithstanding the fact that earlier writers have taken another view.

These sexual organs in their growth, push a layer of peritoneum before them just as do the other outgrowths in the body. Such peritoneum covering the male gonad, which serves as a support for the testes is called a **mesorchium,** while that supporting the ovaries is known as a **mesovarium.** In all the higher forms gonads are paired. In many fishes and birds they are **unpaired,** but this is due to a fusion of two or degeneration on one side.

We have seen in our embryological study how the eggs are formed in the female and lie within a **Graafian follicle** which, after rupture, leaves a scar in the form of a **corpus luteum,** while in the male, instead of the primordial ova and the epithelial cells becoming separate follicles they develop into a **cord** which later on has a lumen open through it and becomes the **seminiferous** tubule. Both epithelial cells and primordial spermatagonia may be found in the walls of this tubule. A third type, known as **Sertoli's cell,** is also found here. These latter are called **nutritive** or **nurse cells** for the developing spermatozoa. Just what function, aside from this supposed nursing, these cells have is unknown. The testes remain in the position where they first appear in most vertebrates, while in nearly all the mammals they descend, assuming a position outside the body cavity, being enclosed in a special pouch called the scrotum.

THE REPRODUCTIVE DUCTS.

As fertilization is necessary in at least all the higher forms of animals, there must be some method by which the sperm or the eggs as well as the young in viviparous animals may be carried to the outside of the body. The sperm-ducts of the mammal are known as **vasa deferentia.** (Fig. 457.) The egg ducts of the female are called **oviducts (Fallopian tubes).** The vasa deferentia are usually the Wolffian ducts, but in the female the oviducts may be **either the Müllerian ducts,** or **specially developed tubes** or even merely **abdominal pores.** In practically all the forms we are studying the Wolffian ducts serve as the outlet for the sperm.

At the same time that the tubules, which are to carry the sperm, are developing, there is an outgrowth of cells from the Bowman's capsules at the cephalic end of the mesonephros, forming what are called **medullary cords.** These latter continue their growth into the **genital ridge** until they connect with the **seminiferous tubules.** All of these acquire a lumen and both together form a continuous transverse tubule, known as the **vas efferens.** (Fig. 458.) This continuous tube leads from the genital cells to the Malpighian corpuscles and thence by the mesonephric tubules to the Wolffian duct. The vasa efferentia become connected by a longitudinal canal before actually entering the Wolffian body; and there is also usually a second longitudinal canal which connects them in the body of the testes. The connection of testis

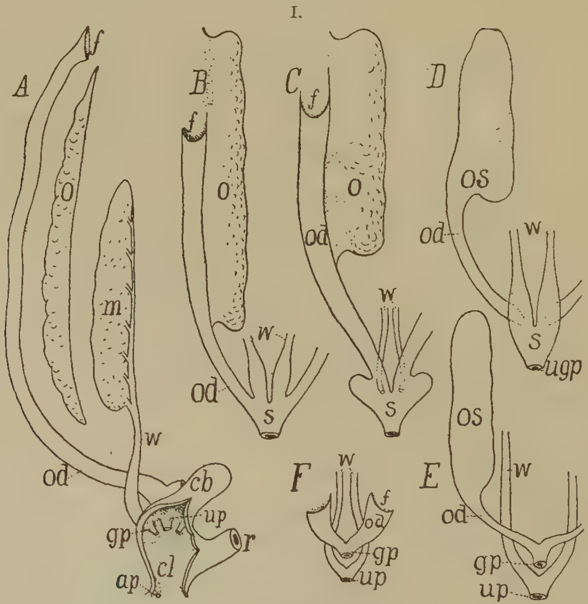

Fig. 457.

I, Diagrams of urogenital systems of female fishes. *A*, African lungfish *Protopterus; B*, African ganoid *Polypterus;* American ganoid *Amia; D*, the garpike *Lepidosteus; E*, most teleosts; *F*, trout and salmon. *ap*, abdominal pore; *cb*, cloacal bladder; *cl*, cloaca; *f*, funnel of oviduct; *gp*, genital pore or papilla; *m*, mesonephros; *o*, ovary; *od*, oviduct; *r*, rectum; *s*, urogenital sinus; *up*, urinary pore (papilla); *ugp*, urogential pore (papilla); *w*, Wolffian ducts. (From Kingsley after Goodrich.)

II.

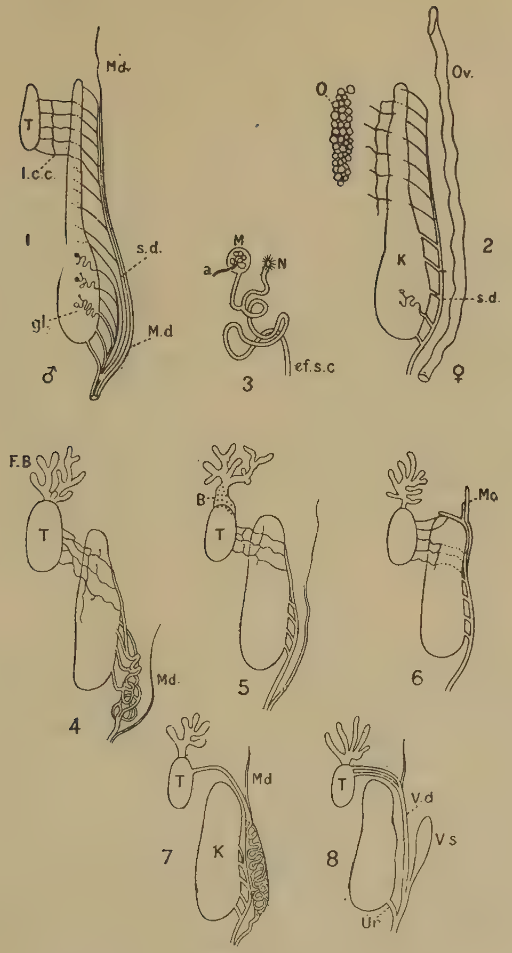

Fig. 457.

II. Diagrammatic representation of the modifications of the urogenital ducts. 1, 2, male and female Newt. 3, a tubule of the kidney. 4, Male Frog. 5, Male Toad. 6, Male *Bombinator* (European Frog). 7, Male *Discoglossus* (Fire-bellied toad). 8, Male *Alytes* (obstetrical toad). *d*, artery entering and producing a coil in the Malpighian body, *M; B*, Bidder's organ; *ef.s.c.*, efferent segmental canal; *F.B*, fat-body; *gl*, glomerulus; *K*, kidney; *l.c.c.*, longitudinal collecting tubule; *M*, Malpighian body; *Md*, Müllerian duct; *N*, nephrostome; *O*, ovary; *ov*, oviduct; *s.d.*, segmental duct; *T*, testis; *Ur*, ureter; *V.d.*, vas deferens; *V.s.*, seminal vesicle. (After Gadow.)

and Wolffian body, while usually taking place at the cephalic end of the mesonephros, may, as in some of the lung fishes, take place at the caudal end.

At about this time the glomeruli of the tubules degenerate. This means that the part of the mesonephros in which these glomeruli degenerate is no longer excretory, but has become a part of the **repro-**

ductive system. It will be noted, then, that sperm can pass throughout the lumen of a tube the entire distance from the origin to its exit from the body.

The cephalic end of the Wolffian duct also becomes purely reproductive in the male, it being considerably coiled to form the **epididymis.** (Fig. 458.) In the amniotes, where the hinder portion of the mesonephros is supplanted by the true kidney (metanephros), the whole Wolffian duct is a sperm duct (vas deferens) in the male, while in the female it largely or completely degenerates. In the amphibia and elasmobranchs the hinder end of the duct is both reproductive and excretory in the male. In the female it is purely excretory.

"In the ichthyopsida, other than elasmobranchs and amphibia, the sperm is carried to the exterior in other ways, and there is no connection of the testes with the excretory organs. In the cyclostomes the sperm escapes from the testes into the coelom and then is passed to the exterior by way of the abdominal pores which in the lampreys open into a cavity (**sinus urogenitalis,** Fig. 457) which also receives the hinder ends of the Wolffian ducts. In the myxinoids the pores are united, and they open to the exterior behind the anus and between it and the urinary openings."

OVIDUCTS

As already stated, in many forms the Müllerian duct is the direct result of the splitting in two of the pronephric duct which then serves as the oviduct. At its separation from the Wolffian duct the Müllerian duct opens into the coelom by means of the pronephric tubules and their nephrostomes. These then flow together and form a larger opening called the **ostium tubae abdominale,** on each side. (Fig. 458.) In the elasmobranchs the ostia are usually united ventral to the liver. The eggs which are thrown out of the ovaries into the coelom are picked up by the somewhat trumpet shaped extensions around the ostia and carried into the oviduct. In some forms the pronephric tubules and nephrostomes take part in the formation of the ostium tubae and the beginning of the oviduct; however, as in all the higher forms, the rest of the oviduct arises by the formation of a groove of the peritoneal membrane close beside the Wolffian duct. This becomes rolled into a tube, the Müllerian duct. In the amniotes the anterior end of the groove does not close, but remains open as the ostium tubae. (Fig. 458.)

It is difficult to trace the successive stages from the most primitive to the most highly developed. By some the condition of the oviduct in the elasmobranchs is regarded as the most primitive. Some contend that we have here a homologous condition—a condition resulting from similar primitive structures; others that it is rather analogous and an example of convergent evolution in that these organs, having been used for similar functions, have come to appear somewhat alike structurally.

It can be seen how difficult valid comparisons are when we have such varying conditions in the lower, but nevertheless supposedly related forms, as this: In the cyclostomes the eggs are thrown from the ovaries directly into the coelom, being passed out through abdominal pores, but in the teleosts alone there are several conditions, the ovaries of some are

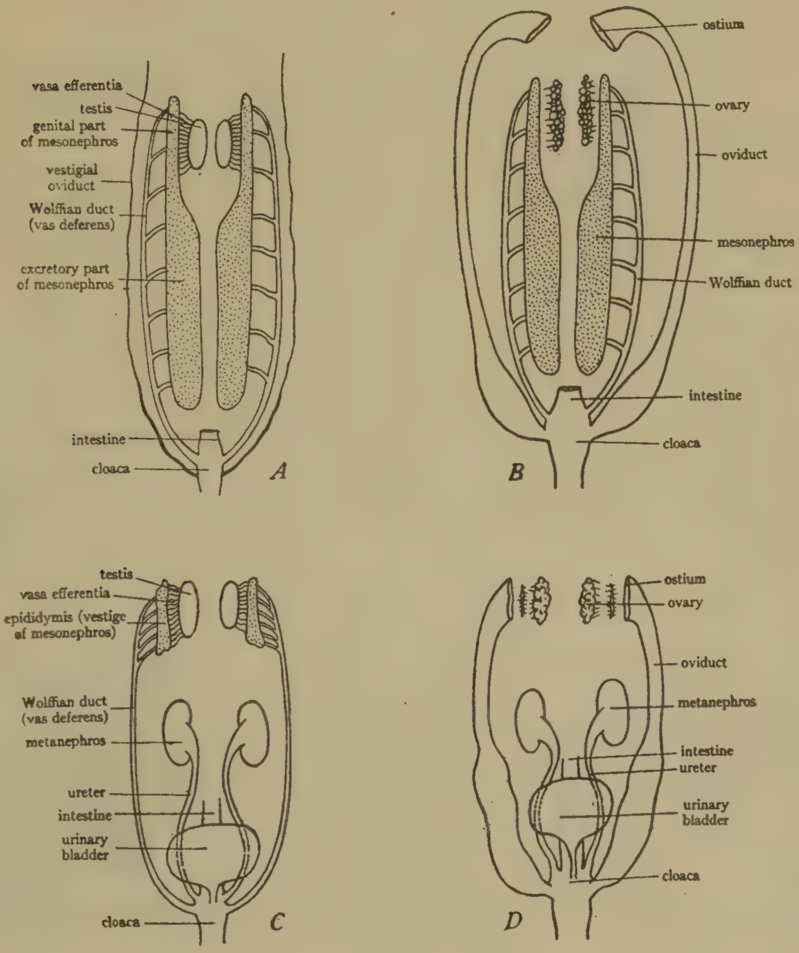

Fig. 458.

Diagrams to illustrate the urogenital system of male and female anamniotes and amniotes. *A*, male elasmobranch or amphibian; the mesonepheros is differentiated into anterior genital and posterio-excretory portions; the genital part is connected with the testis by means of the vasa efferentia, which are outgrowths from the mesonepheros, the mesonepheric or Wolffian duct serves as both genital and excretory duct; the oviduct or Müllerian duct is vestigial. *B*, female elasmobranch or amphibian; the ovary is not connected with the mesonephros; the mesonephros and mesonephric duct serve only excretory functions; the oviduct is well developed and opens into the coelom by the ostium near the ovary. *C*, male reptile, bird, or mammal. The excretory part of the mesonephros has disappeared but the genital part persists as the epididymis (in part) which is connected as in anamniotes with the testis by means of the vasa efferentia; the Wolffian duct is purely genital and is renamed the vas deferens; the excretory function is served by the metanephroi and ureters. *D*, female reptile, bird or mammal; the mesonephros and Wolffian duct have entirely vanished; the condition of the ovary and oviduct is the same as in anamniotes; the excretory function is served by the metanephroi and ureters exactly as in the male. (From Hyman's modification of Wilder.)

simple and composed of solid bands or are sac-like, having an internal lumen. In the simple forms the eggs pass into the coelom and thence to the exterior by abdominal pores or by oviducts of varying lengths. We do not know whether these ducts are true Müllerian ducts or whether they are new formations.

The sacular condition of the ovaries may come about by the free edge of the ovary bending laterally and fusing with the wall of the coelom. This forms a cavity called the **parovarial canal,** closed in front. Or there may be a groove in the covering epithelium forming on the surface of the ovary. In this case, as it closes and sinks inward, it forms what is called an **entovarial canal.** In either case the canal may extend to the most caudal end of the body cavity and form an oviduct in this manner, "or the oviduct may be formed from both kinds of canals, one in front, the other behind."

"From this it would appear that the ovary originally extended back to the hinder end of the coelom (as it does in **Cyclopterus)** or that the par- or entovarial canal had united with a Müllerian duct which has otherwise been entirely lost. The oviducts thus formed usually unite before opening to the exterior, either directly or via a urogenital sinus."

It will be remembered that there are **shell glands** (likewise called **nidamental glands)** in those animals which are oviparous, although these may appear in viviparous forms also, though they are very slight in these latter instances. It is interesting to note that in some species of elasmobranchs the eggs are larger than those of an ostrich. In this same type of animal the caudal or inner side of the pelvic fin is specialized for a copulatory organ, for in the elasmobranch fertilization is internal. In the amphibia there are many interesting accessory reproductive relations as mentioned in the chapter on classification of vertebrates. The caecilians and **Amphiuma** lay their eggs in long strings in the soil and the female incubates them although the male often takes charge of the eggs. In **Pipa** each egg undergoes development in a pit in the skin of the back of the female, and in **Nototrema** and **Opisthodelphys** (South American tree-toads), there is a large pocket in the skin of the back, opening near the coccyx, where the eggs are carried until partially **(Nototrema)** or entirely developed. **Salamandra maculosa** and **S. atra** bring forth living young, the former possessing gills at birth, the latter in the adult form.

In the higher forms of vertebrates there is a definite single copulatory organ. Among the sauropsida the **Sphenodon** alone lacks all copulatory organs, while in most birds they are incomplete. The males of crocodiles, turtles, ostriches, ducks, geese, and swans are among the very few that have a definite structure homologous to that of mammals for this purpose. In snakes and lizards several sacs are developed from the caudal wall of the transverse anus. They resemble appendages in the embryo and form real copulatory organs called hemipenes. They are present in both sexes though very small in the female. As growth continues, retractor muscles are developed which draw the organ back into pockets where they are retained at all times except when used for copulation. The simplest form of the copulatory organ is produced by a thickening of the ventral wall of the cloaca. There is a longitudinal groove formed in the upper surface of this through which the sperm may pass. It may be divided into right and left halves, the tip of which forms the glans penis. The homologous structure is the clitoris which forms in the female though all parts but the glans are lacking.

In the mammals, while there are two pronephric tubules outlined in the embryo, they never are functional and the pronephros degenerates. The mesonephros, however, is definitely used during foetal life, and in the marsupials and monotremes it even functions sometimes after birth. However, in all forms of mammals it disappears in time, with the exception of the efferent ductules of the testes and a few remnants in both sexes. The metanephros, which becomes the permanent kidney, has several lobes in the early stages. A definite lobe is formed for each end branch of the ureter so that each lobule has its own duct. This condition is retained in "adult elephants, some ungulates, carnivores and primates, and especially in the aquatic species (whales, seals), the lobules being most numerous (200+) in some whales. In all other species the ducts fuse and the lobules unite later into a compact mass lying in the lumbar region near the last rib." These lobules are the cause of the cortex and medulla of the kidneys forming two series of interlocking pyramids. (Fig. 459.)

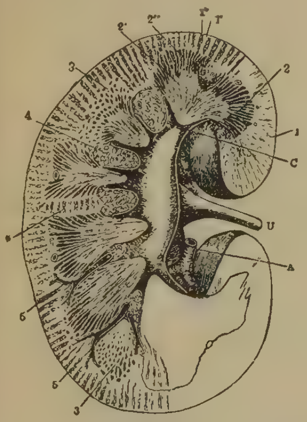

Fig. 459.

Longitudinal section through kidney. 1, cortex, 1′, medullary rays; 1″, labyrinth; 2, medulla; 2′, papillary portion of medulla; 2″, boundary of medulla; 3, transverse section of tubules in the boundary layer; 4, fat of renal sinus; 5, artery; transverse medullary rays; *A*, branch of renal artery; *C*, renal calyx; *U*, ureter. The pyramids are located between the fat portions and form the papillae. (From Hill after Tyson and Henle.)

In the early embryonic stages the gonads lie cephalad to the kidneys.

The ovaries are usually equally developed in the mammals, except in the monotremes where the left is the larger. "It is of interest that eggs—one in the **Echidna,** two in **Ornithorhynchus**—have been found only in the left oviduct." The ovaries, contrary to the testes, always remain in the body, and in the monotremes retain their early position. "They are supported by the mesovaria which are attached to the median side of the double fold of the peritoneum which supports the mesonephros. When the Wolffian body degenerates, the fold becomes the **broad ligament** while another fold continues down the Müllerian duct as the **ligament of the ovary.** In some mammals the ovaries have, in addition, a special fold of the peritoneum, which in the rats and mice encloses the ovary and the ostium tubae connected with its opening."

"The testes are relatively small and are shaped much like the ovaries and at first they are at about the same level. The outer surface is smooth, a fibrous envelope, the tunica albuginea, having developed around them, which sends trabeculae inward, dividing the seminiferous tubules into lobules. Except in the monotremes the testes descend farther into the pelvic cavity, remaining permanently in the pelvis in many insectivores, some edentates, elephants, whales and **Hyrax.** In other groups they pass outside the pelvic cavity to be enclosed in a special sac, the scrotum. The testes are supported by a cord, the **gubernaculum,** the homologue of both ligaments of the ovary.

"The change in position of ovary and testis is accomplished in part by the unequal growth of body wall and the supporting ligaments. In the case of the male this **descent of the testes** is complicated. (Fig. 460.) In outline it is as follows: By the unequal growth of gubernaculum and body wall the testes are drawn down into the scrotum which is a protruding part of the body wall into which a part of the coelom extends. This wall is formed in part from the genital folds which surround the genital eminence. It lies in front of the penis in the marsupials, behind it in all placental mammals. When the canal connecting the cavity of the scrotum **(bursa inguinalis)** remains open as it does in marsupials, bats, rodents, insectivores, etc., the descent is temporary, the testes being withdrawn into the peritoneal cavity at the close of the breeding season by the **cremaster muscle,** developed from the transverse abdominal muscle. In other mammals the descent is permanent, though sometimes it does not occur until the time of sexual maturity."

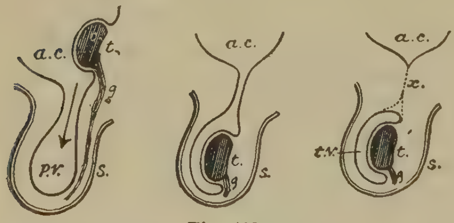

Fig. 460.

Descent of the testis *ac*, abdominal cavity; *g*, gubernaculum; *pv*; processus vaginalis; *t*, testis; *s*, scrotum; *tv*, tunica vaginalis; *x*, rudiment of processus vaginalis.

In the monotremes the Müllerian duct is divided into a cephalic portion known as the **Fallopian tube** and a caudal portion, the **uterus,** although the line separating these two is not very definite. The broad trumpet-shaped end of the Fallopian tube connects with the coelom while the tube itself secretes the albuminous covering of the eggs. The uterus is more muscular than the Fallopian tube and it is here that the horny shell is formed. The uterus then opens directly into the urogenital sinus to connect the cloaca with the exterior.

In other forms of mammals the end of the Müllerian duct between the uterus and the urogenital sinus forms a vagina. In marsupials there are two vaginae and sometimes three.

When the two caudal ends of the Müllerian ducts fuse as in many placental animals such as in rodents, there are two uteri formed each with a separate opening into the vagina. (Fig. 461.) In the carnivores and ruminants where the fusion is carried still farther back, forming in reality two uteri with only one opening it is called a **uterus bipartibus,** or where it is carried still farther forming two horns it is called **uterus bicornuus.** For the **uterus simplex** the fusion is entirely complete, as in all primates, the two Fallopian tubes alone remaining as evidence of its bilateral formation.

In the female the Wolffian duct and the mesonephros are largely lost in the adult, the mesonephros forming a small collection of tubules near the anterior end of the ovary which is known as the **parovarium.** In the male the Müllerian duct is also largely lost, the lower portion sometimes persisting as a small blind tubule imbedded in the prostate gland and known as the **uterus masculinus.** (Fig. 462.)

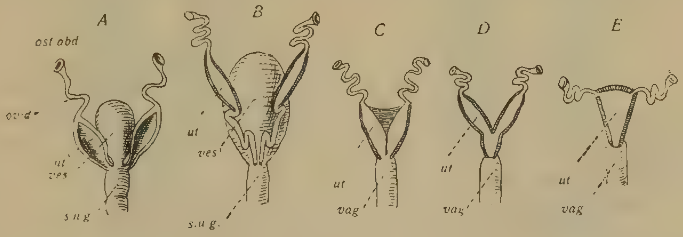

Fig. 461.

Five varying uteri. ***A Monotreme; B, Marsupials; C,*** **duplex uterus;** ***D,*** **bicornuate uterus, and** ***E,*** **Simple uterus.** ***ost.abd.,*** **abdominal opening (ostium) into oviduct;** ***ovid.,*** **oviduct;** ***s.u.g.,*** **urogenital sinus;** ***ut,*** **uterus;** ***vag.,*** **vagina;** ***ves.,*** **urinary bladder. Such uteri as** ***A*** **and** ***B*** **open into the urogenital sinus, while** ***C, D,*** **and** ***E,*** **open into the vagina. (After M. Weber.)**

Between the tubules in the testes there are small aggregates of cells known as **interstitial cells,** which are glands of internal secretion. In man their products, which pass into the blood, apparently cause the assumption of the secondary male characters—growth of hair on the face, change of voice, etc.—at the time of puberty. There would also seem to be some analogous structure in the ovary governing the development of female characteristics and controlling some of the features of menstruation.

There are also a number of accessory glands (Fig. 462) connected with the genital ducts, usually better developed in the male than in the female. The more prominent ones are: the **seminal vesicles** (present in some rodents, bats, insectivores and in ungulates and primates) are a pair of tubular or saccular glands opening into the vasa deferentia just before these enter into the urogenital canal; the **prostate glands,** (occuring in all placental mammals with the exception of edentates and whales) are connected with the urogenital canal, while farther along the canal **Cowper's glands** are found. These occur in almost all mammals as scattered bodies or aggregated into larger masses surrounded by smooth muscle.

Considerable uncertainty exists as to the exact functions of these glands. The removal of the prostate and the seminal vesicle in rats prevents fertilization, while the secretion of the seminal vesicles increases the activity of the spermatozoa. It seems probable that they are of great importance in connection with fertilization. It has also recently been shown that in some instances the coagulation of the secretion of these glands closes the vagina after copulation and, thus prevents the exit of the sperm.

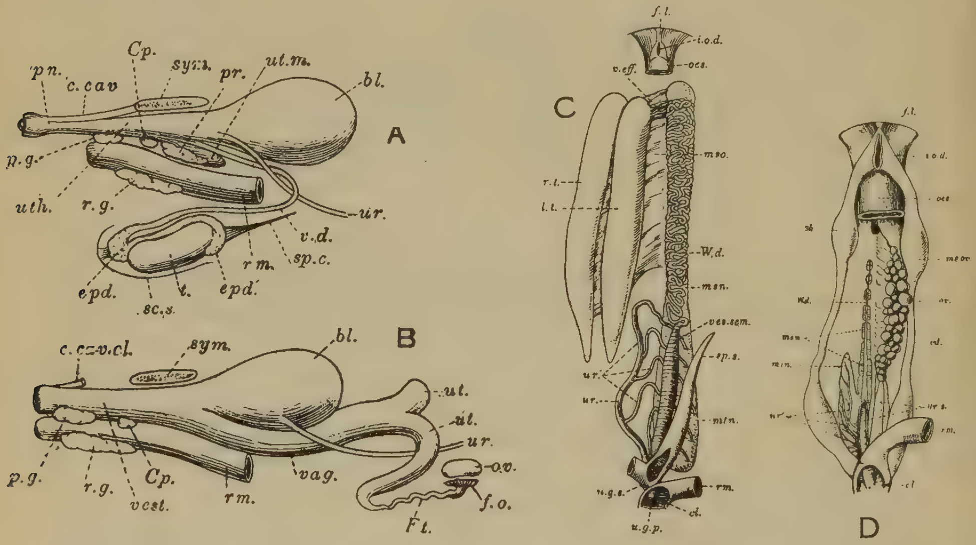

Fig. 462.

A, *B*, The reproductive organs of the rabbit. *A*, male; *B*, female. In each case the dissection is made from the left side, the animal lying on its back. *bl.*, Bladder; *c.cav.*, corpus cavernosum; *c.cav.cl.*, corpus cavernosum of the clitoris; *Cp.*, Cowper's gland; *epd.*, cauda epididymis; *epd'.*, caput epididymis; *F.t.*, Fallopian tube; *f.o.*, fimbriated opening of the same; *ov.*, ovary; *p.g.*, perineal gland; *pn.*, penis; *pr.*, prostate; *r.g.*, rectal gland; *rm.*, rectum; *sc.s.*, scrotal sac; *sp.c.*, spermatic cord (cut short); *sym.*, symphysis pubis; *t.*, testis; *ur*, ureter; *ut.*, uterus; *ut.m.*, uterus masculinus; *uth.*, urethra; *v.d.*, vas deferens; *vag.*, vagina; *vest.*, vestibule.

C, male, and *D*, female reproductive organs of dogfish. *cl.*, Cloaca; *f.l.*, "falciform" ligament; *i.o.d.*, rudiment of the internal opening of the oviducts; *l.t.*, left testis; *msn.*, mesonephros; *mso.*, mesorchium; *mtn.*, metanephros; *od.*, oviduct; *oes.*, oesophagus; *ov.*, ovary; *r.t.*, right testis; *rm.*, rectum; *sh*, shell gland; *sp.s.*, sperm sac; *u.g.p.* and *v.p.*, urinogenital papilla; *u.g.s.* and *ur.s.*, urinogenital sinus; *ur.*, ureter; *ur'.*, ducts of metanephros; *v.eff.*, vasa efferentia; *ves.sem.*, vesicula seminalis; *W.d.*, Wolffian duct or vas deferens.

In the monotremes the cloaca serves as a general gathering place for both the products of the urogenital sinus and the excreted matter from the digestive canal and kidneys. This cloaca has only a single opening to the exterior and it is from this fact that the name monotreme has been taken. In all other mammals there is a definite and complete separation of the faecal and urogenital matter. This separation is brought about by a horizontal partition dividing the cloaca into a dorsal rectum and a ventral urogenital portion. This space between rectum and urogenital portion is called the **perineum.**

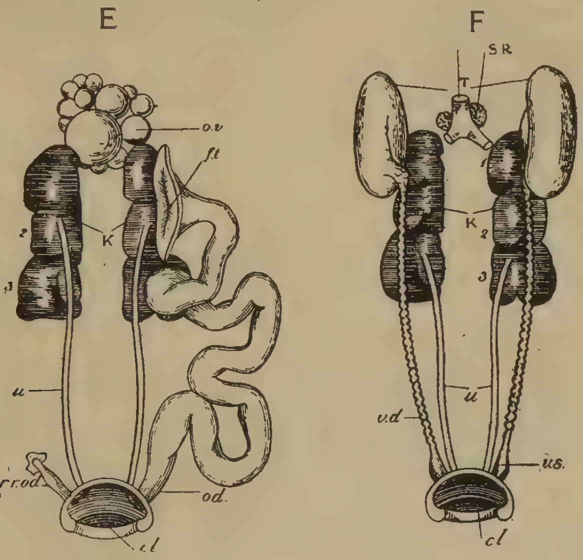

Fig. 462.

E, The urogenital organs of a female pigeon. *K.*, kidney (metanephros) with three lobes; *u.*, ureter; *cl.*, cloaca; *ov.*, ovary; *od.*, oviduct; *f.t.*, funnel at end of oviduct; *r.r.od.*, rudimentary right oviduct.

F, The urogenital organs of a male pigeon. *T.*, testes; *V.*, base of inferior vena cava; *S.R.*, suprarenal glands; *K.*, kidneys with three lobes (1, 2, 3); *u.*, ureter; *v.d.*, vas deferens; *v.s.*, seminal vesicle; *cl.*, cloaca. (*A*, *B*, *C*, *D*, from Borradaile, *E*, *F*, from Thomson.)

ORGANS OF COPULATION.

In both sexes of mammals the same anlagen of the external genitalia are found as already studied in embryology. These consist of a genital prominence which is formed from the ventral or anterior wall of the cloaca. This then protrudes from the opening and, when the perineum is formed, two thickenings appear on each side, a medial genital fold and a larger and lateral genital ridge, which extends back nearly to the level of the anus. The genital prominence never develops much farther in the female, while the folds and ridges become the labia minora and majora. In the male, however a groove is formed on the primitively dorsal surface of the prominence which continues into the cloaca. Then the folds grow together behind the prominence, closing the groove to a tube, the **urethra,** while the prominence becomes the glans penis. A similar growth of the genital ridges toward the median line results in the formation of the outer wall of the scrotum.

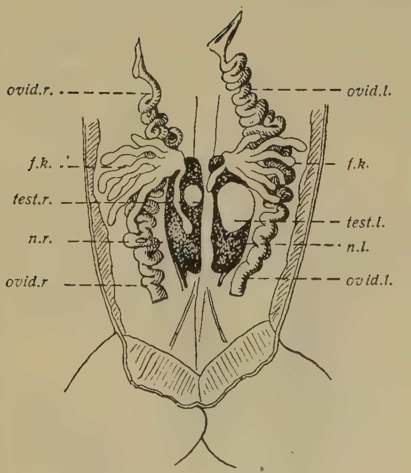

Fig. 463.

Hermaphrodite Frog. *f.k.*, fat-bodies; *n.l.* and *n.r.*, left and right mesonephroi; *ovid.l.* and *ovid.r.*, left and right oviducts; *test.l.* and *test.r.*, left and right testes. (After Mitrophanoff.)

While internal fertilization takes place in most of the higher forms of animals, there are many vertebrates such as the cyclostomes, most fishes with the exception of the elasmobranchs, and many amphibia in which fertilization does not take place until after the eggs have passed from the body of the female. The organs by which sperm is passed to the female are formed in many ways and are not considered homologous in the different forms.

As we already know from our study of the earthworm, there are animals possessing both ovaries and testes. Such animals are commonly termed **hermaphrodites.** True hermaphrodites must have both ovaries and testes **functional.** (Fig 463.)

It is interesting to note that while there are occasional hermaphrodites among the lampreys, this is a rather common occurrence in the myxinoids. In these the cephalic end of the gonad is male, and the caudal end female. However, usually one or the other of these functions, so that the animal is either predominantly male or female. Hermaphroditism has been found among the frogs, while in toads there is often a "**Bidder's organ**" lying directly in front of the gonads of the male but containing immature ova. (Fig. 457.) Cases of hermaphroditism, although possible, are seldom found in mammals, the so-called cases being merely arrested growth in the male, preventing the two portions of the scrotum from joining in the mid-line, or an hypertrophy of the clitoris in the female.

ADRENAL ORGANS.

Closely associated with the nephridial structures lie two small ductless glands, one connected with each renal organ in the higher forms. In the lower vertebrates each one of these is in turn composed of two structures. In the amphibia and amniotes one portion, called the **suprarenal,** forms the medulla while the **interrenal** forms the cortex of the mammalian adrenals. (Fig 351.) The suprarenal portion is always connected with the sympathetic nerve ganglia, some of the cells always retaining their nervous character. Other cells, because they stain brown or yellow with chromic salts are called **chromaphile** or **phaeochrome cells** (Fig. 464.) These are usually quite closely related to blood vessels.

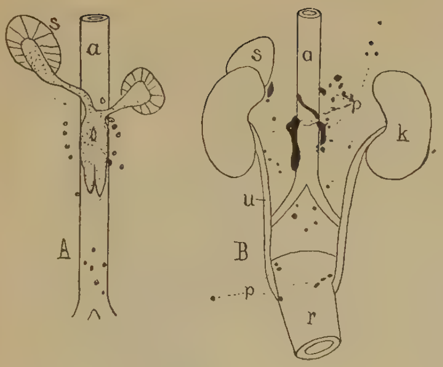

Fig. 464.

A, The phaeochrome system of a just-born rabbit. *B*, The same in a forty-five day girl. *a*, aorta; *k*, kidney; *p*, phaeochrome bodies; *r*, rectum; *s*, suprarenal; *u*, ureter. The connection between the bodies and the central portion of the suprarenal is shown in *A*. (From Kingsley after Kohn.)

The interrenals arise from the epithelium of the coelom, there being as yet considerable doubt as to whether they are connected with pro- or meso-nephros, or whether they are totally distinct in origin. They arise as isolated clusters or bands of cells near the dorsal margin of the mesentery. Sometimes they are bilaterally symmetrical, and in the lower vertebrates may extend throughout the entire length of the coelom in the early stages.

Both interrenals and suprarenals are separate in the fishes. The interrenals are the more compact of the two and lie between the excretory organs of the two sides of the body.

The suprarenal tissue forms the medulla of the adrenals from a series of tubules through which the blood from the suprarenal artery circulates before it is carried away by the vein. The adrenals are closely associated with the Wolffian bodies in amphibia, (Fig. 351) either being attached to the inner margins (urodeles), or forming yellow stripes (anura) on the ventral surface. In the reptiles they are lobulated bodies near the gonads.

It is from the medullary portion in mammals that **adrenalin,** sometimes also called **epinephrin,** is procured. This is an **activator** or **hormone,** which acts directly on the muscles and causes an increase in blood pressure.

SUMMARY OF THE UROGENITAL SYSTEM.

Fishes (Fig. 457):

The excretory system consists of elongated bodies situated in the median dorsal part of the coelom. These bodies are composed of nephric tubules that have funnel-like nephrostomes opening into the coelom. The functional kidney is a **mesonephros.** The ovaries and testes (with the exception of the teleosts) are sac-like structures that have ducts, oviducts and vasa efferentia developed in connection with the primitive nephridial duct, as in other groups.

In teleosts there are no vasa efferentia or true oviducts, for the posterior ends of both testes and ovaries are continued into a duct direct; the duct from the testes unites with its fellow on the opposite side to empty into either a urogenital sinus or directly to the outside, and the one from the ovary takes the eggs direct from the ovary before they enter the coelom as in most of the higher forms.

The eggs of different fishes range from large heavily-yolked eggs with chitinous shells, as in the modern elasmobranchs, to the small pelagic eggs of many modern teleosts. The eggs pass out through the ducts of teleosts as mentioned in the preceding paragraph or through abdominal pores as in ganoids and in some **Physostomi.**

For the most part, fish-eggs are fertilized in the open water, although there are many orders which practice internal impregnation and are viviparous.

Most of the teleosts are dioecious but some are hermaphroditic. **Serranus,** a member of the Perch family is even self-impregnating, while **Chrysophrys** is successively male and female, while cod and herring often exhibit the hermaphrodite condition, though this is abnormal.

Dogfish (Fig 462):

The pronephros is never functional as an excretory organ. The nephrostomes fuse to form the **ostium tubae** in the female.

The pronephric duct splits into both a Wolffian and a Müllerian duct. The nephrostomes close in the adult. The anterior end of each mesonephros is narrowed and in the male this connects with the anterior end of the Wolffian duct to form a connection with the testes. The epididymis consists of the coiled anterior end of this connection.

The Müllerian ducts become known as oviducts. The oviducts of both sides connect with the coelom. The common opening thus formed is the **ostium tubae abdominale.**

The eggs leave the ovary, pass to the ostium and are then carried backward to a shell-gland. The enlarged portion of the tube forms the uterus.

In the male, the anterior end of the mesonephros forms the epididymis while the vasa deferentia of both sides unite to form a **urogenital sinus.** There is an oval sperm-sac connected on each side. Fertilization is internal.

The suprarenals are metameric and may be imbedded in the mesonephroi.

Amphibia (Fig. 457):

The pronephros functions until metamorphosis. The tubules then degenerate. In the adult frog and other tailless amphibians the nephrostomes of the mesonephros separate from the nephridial tubules to join with branches of the renal blood vessels so that the coelom is in direct connection with the excretory system.

The Wolffian duct carries the nephridial waste and the same duct also acts as the vas deferens in the male just as it does in the dogfish. Where these ducts enter the cloaca there is an enlargement on each to form the **seminal vesicle.**

The urinary bladder is ventral to the cloaca. The eggs pass into the body cavity and thence into the **ostium tubae.**

Fertilization is external in the tailless amphibians but internal in tailed amphibians. The male of the tailed amphibians secretes a substance which binds the spermatozoa into little packets called **spermatophores.** There are various accessory reproductive relations as mentioned in the chapter on classification.

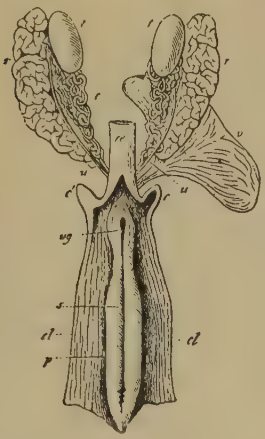

Fig. 465.

Cloaca and urogenital organs of a turtle, *Chelydra serpentina. c, c'*, blind sacs of cloaca; *cl*, cloaca; *e*, epididymis and vas deferens; *p*, penis, *r*, kidneys; *re*, rectum; *s*, groove on penis; *t*, testis; *u*, ureter; *ug.*, cloacal opening of bladder; *v*, bladder. (From Sedgwick's Zoology, after Gegenbaur.)

Reptilia and Aves (Figs. 462, 465):

The kidneys are **metanephric bodies** which pass their excretion through paired ureters directly to the cloaca in the reptiles and from here into a **urinary bladder** which, in turn, empties into the **cloaca.** The pronephros never functions, and the mesonephros (always lacking nephrostomes) may function after hatching for a time in some reptiles. In the female the mesonephros, after degenerating, is preserved as the "yellow-body." The male reproductive organs consist of a pair of testes, a pair of much coiled vasa deferentia through which the sperm passes to the grooved penis; the latter organ being attached to the front of the cloaca. The female organs consist of paired ovaries and large oviducts, provided with albuminous and shell glands. The eggs when laid are covered with a tough shell, and those of reptiles are usually buried in the ground. Many reptiles are, however, viviparous. The Wolffian duct is the urinary tube while the mesonephros functions, but later degenerates in the female. It persists in the male as the vas deferens.

In birds the left ovary alone remains functional.

Mammalia:

Only two pronephric tubules form and these never function. The mesonephroi function in foetal life and in marsupials and monotremes for sometime after birth. Nephrostomes never form except in **Echidna.** In some rodents no glomeruli occur. The kidneys are of the **metanephros type.** They are usually asymmetrical in position, one lying anterior to the other. The ureters lead directly to the urinary bladder, which is formed out of the remains of the allantois.

The ovaries are never single as in birds. They are very small on account of producing minute eggs with little or no yolk. This small size of ovaries and eggs is well fitted to the habit of uterine gestation. The paired oviducts enlarge to form paired uteri and in some groups these unite into a single median uterus.

The testes at first lie in the body cavity as in reptiles, and occupy positions homologous with those of the ovaries. In most mammals with the exception of monotremes, whales, elephants, armadillos, and a few others, the testes descend into the scrotum. The penis of the male mammal is homologous with the clitoris of the female.

CHAPTER LV.

THE MUSCULAR SYSTEM.

The general Muscular system has been discussed in considerable detail in our study of the frog while the development of the muscles was taken up in the study of embryology.

It will be remembered that histologically there are **voluntary** and **involuntary** muscles, the former being **striated,** the latter smooth, while the heart muscles are a sort of combination of these two.

The smooth muscles have their beginnings **in mesenchyme,** and, being involuntary, are **innervated by the sympathetic nervous system.** Their action is also much slower than that of the striated muscle. They are found in the skin, in the walls of blood vessels, in the walls of the digestive canal and in the urogenital system.

The striated muscles have their origin in the walls of the coelom and are of **mesothelial origin.** They are supplied by the **motor nerves of the central nervous system.** They are all voluntary except those at the more cephalic end of the digestive tract. Striated fibres may be found in the body walls, in all organs of locomotion, in the head, in the diaphragm, and in the cephalic end of the alimentary canal.

The voluntary muscles arise from the somites (which divide into myotomes and lateral plates, after the epimeres have given rise to the sclerotomes and dermatomes).

The myotome grows downward between the hypomere and the skin to meet its fellow on the opposite side in the median ventral line. This produces a completed coat of voluntary muscles which lies beneath the skin. The muscle coat is divided into a dorsal and ventral part by the horizontal skeletogenous partition (Fig. 423) which intersects the skin at the lateral line. The dorsal muscles are called **epaxial,** and those ventral to the septum, **hypaxial.**

The muscles originating from the lateral plates, in the gill-arch region, which move the gill arches are called **visceral muscles.**

The muscles originating from the myotomes are called **parietal** or **somatic muscles.**

All muscles except the diaphragm and heart (the heart is always included under the circulatory system) are divided into three groups known as **parietal, visceral,** and **dermal** muscles.

From our embryological study it will be remembered that the myotomes were cut off from the walls of the coelom, each one forming a closed sac, the inner wall being called the **splanchnic layer** and the outer the **somatic layer.** The more dorsal cells of the splanchnic layer develop many nuclei which can be seen in the interior of the cell in the lower vertebrates. They are quite close to the surface in the muscle fibres of mammals. Each myotome has its splanchnic wall converted into a muscle so that there are as many primitive muscles as there were myotomes.

The somatic wall of the myotomes does not become muscle but changes into mesenchyme from which the corium of the skin develops. Some of the mesenchyme protrudes between the various myotomes and there forms fibrous connective tissues that later become the ligaments which connect the various muscles of a side.

This primitive muscle segmentation can still be seen in the intercostal and rectus abdominis muscles.

The myotomes lie close to the level of the notochord and spinal cord, but they grow both dorsally and ventrally, working their way between the skin and the walls of the coelom to become an actual part of the somatopleure.

Ventrally the muscles from both sides grow toward each other and practically meet at the mid-ventral line, the direct mid-ventral line which is filled with connective tissues being known as the **linea alba.**

In the fishes the trunk and tail muscles are arranged in myomeres which take a zig-zag course. (Fig 401). The muscles are divided horizontally into dorsal and ventral portions (Fig. 423), the **epaxial** and **hypaxial muscles,** a line of division which follows more or less closely the lateral line. The plates of muscle do not retain their flat ends in the adult, but one end becomes conical and fits into a corresponding hollow in the next plate. In the tail of the amphibia epaxial and hypaxial muscles are clearly recognizable, but farther forward the hypaxials are greatly reduced, and in the amniotes the reduction is carried so far that the epaxial muscles, greatly modified, can only be recognized in the cervical and pelvic regions, the "tender-loin" being epaxial.

The developmental conditions are more complicated in the head than in the trunk. In the head region of fish and birds ten coelomic pouches develop while in amniotes the number is apparently twelve. These are known by number, with the exception of the most anterior, which was not known when the numbers were applied and is called **A.** These coelomic or **head cavities** differ from the myotomes farther back by having no undivided portion of the coelom below, corresponding to the hypomeral zone. This difference is possibly due to the existence of visceral clefts in this region.

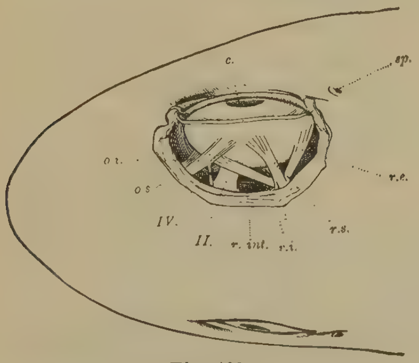

Fig. 466.

The head of a dogfish, seen from above with the right orbit opened. *e.*, eyeball; *o.i.*, *o.s.*, inferior and superior oblique muscles; *r.e.*, *r.int.*, *r.s.*, external, inferior, internal, and superior recti muscles; *s.p.*, spiracle; *II.*, optic nerve; *IV.*, fourth nerve. (From Borradaile).

Four of these cavities lie in front of the ear of which **A** disappears completely, its cells joining the mesenchyme. The other three give rise to the "eye muscles" which move the eye ball. (Fig. 466.) In general, 1, which lies in front of the mouth, gives rise to four muscles, the **inferior oblique** and three of the **rectus muscles**; 2, which lies in the region of the jaws, forms the **superior oblique muscles**; while 3, in the hyoid region, develops the **lateral (external)** rectus (in some animals also a **retractor bulbi).** The origin of these muscles explains the distribution of the eye-muscle-nerves, as each nerve supplies only the derivatives of a single myotome. Several of the other myotomes disappear in development, but the posterior becomes the so-called **hypoglossal musculature.**

We have been describing only the origin of the **contractile tissue** of the muscles. There is also a connective tissue to be considered.

Mesenchyme cells invade the muscle fibres to form envelopes **(perimysium)** which bind the fibres into bundles **(fasciculi),** these in turn, are united by other envelopes called **fascia.** These connective-tissue envelopes continue beyond where the contractile tissue leaves off to form the **cords** or **tendons** by which the muscle is attached. The more fixed point of attachment is called the **origin,** the less fixed the **insertion.** Tendons may be of any shape; such as long and slender, so as to allow the muscle to lie in or near the trunk, the part to be moved being in the appendage; or they may form broad flat sheets **(aponeuroses).** These latter may occur not only at the ends but in the middle of a muscle. Sometimes parts of tendons ossify, as in the patella or in the "drum-stick" of the turkey. Such small rounded ossifications of this kind are called **sesamoid bones.** In a few cases, even, as for example, around the eye and mouth of mammals, the parietal muscles are **without attachment.** Here they form rings which are used to diminish the size of an opening **(sphincter muscles).**

Muscles vary considerably as to shape, size, number of "heads" or points of origin, and numbers of contractile portions.

Muscles are usually arranged in **antagonistic groups** so that any given action may likewise be reversed. We thus have flexors to bend a limb and extensors to straighten it; elevators to close the jaw, depressors to open it, etc.

It is rather difficult to trace exact homologies. The test usually considered best is to **trace the nerve supply,** for every muscle derived from a given myotome is innervated by branches of the nerve which also originally connected with that segment. A further test is the origin and insertion. The **action** of a muscle is of little value in a test for homologies.

A difficulty in the drawing of conclusions from specimens before one, comes from the fact that a muscle may split into various layers either longitudinally or transversely, and some even, though entirely different in origin, may fuse together, while others, either in part or in whole, may degenerate and disappear entirely. Should one take **nerve supply** as a guide, as is usually done, it will be seen that the facial muscles, especially those of the higher mammals, have certainly wandered a long way from their embryologic origin.

The names and location of muscles of the frog should be thoroughly reviewed at this point.

In the higher vertebrates the **anterior spinalis** differs from the frog by being divided into several **rectus capitis muscles** which connect the first vertebra with the skull.

The **longissimus dorsi group** lie on each side of the vertebral spines in the angle between spinous and transverse processes and extends from the pelvis to the head. This group is made up of a **longissimus dorsi proper** in the lumbar region, an **ileo-costalis** (inserted on the dorsal part of the ribs), and a **longissimus capitis** along the side of the neck to the temporal region of the skull.

The muscles of the appendages are divided into **intrinsic** and **extrinsic** groups. The former have their origin in or on the appendicular skeleton itself, the latter have their origin on the trunk or axial skeleton and their insertion on the girdle or base of the limb. Intrinsic muscles therefore move parts of the limb; extrinsic move the limb as a whole. Muscles are often divided according to their action as already seen. **Protractors** draw a member forward; **retractors** pull it back against the body; **levators** lift it, and **depressors** pull it down; **flexors** bend a limb or its parts; **extensors** straighten it and **rotators** turn it upon its axis.

Some of the more prominent muscles are as follows:

Levators:

trapezius (for fore limb).
levator scapulae (for fore limb).

Depressors:

pectoralis (for fore limb).
serratus anterior (for fore limb).

Protractors:

pectineus (for hind limb).
adductors (for hind limb).
sternocleidomastoid (for fore limb).
levator scapulae anterior (for fore limb).

Retractors:

pyriformis (for hind limb).
pectoralis minor (for fore limb).
latissimus dorsi (for fore limb).

The pubofemoralis draws the hind limb toward the mid line while the gluteus muscle acts as a retractor and elevator.

THE VISCERAL MUSCLES.

As already stated the gill-bearing vertebrates develop a special system of muscles in connection with the visceral arches which are used

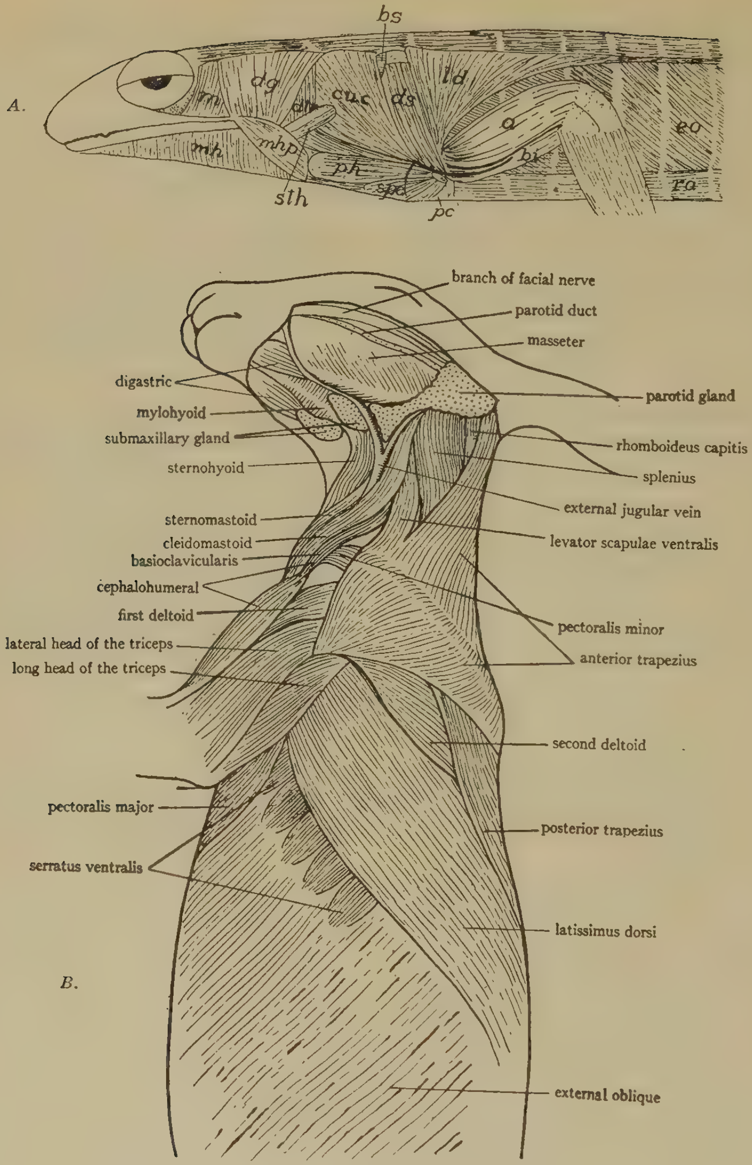

Fig. 467.

A, Superficial muscles of the cephalic part of the tailed amphibian *Salamandra maculata*. *a*, anconeus; *bi*, humero-brachialis inferior (biceps); *be*, levator scapulae; *cuc*, cucularis; *dtr*, dorso-tachealis; *dg*, diagastric; *ds*, dorsalis scapulae; *eo*, external oblique; *ld*, latissimus dorsi; *m*, petro-tympano-maxillaris (masseter); *mh*, mylohyoid; *mhp*, mylohyoid posterior; *pc*, pectoralis; *ph*, procoraco-humeralis; *ra*, rectus abdominis; *spc*, supracoracoid; *sth*, sternohyoid. (From Kingsley after Fürbringer.)

B, Lateral view of the anterior part of the rabbit to show the muscles. The head is turned slightly so as to give a ventral view of the throat. All dermal muscles have been removed. (From Hyman's "A Laboratory Manual for Comparative Vertebrate Anatomy," by permission of the University of Chicago Press.)

for the purpose of opening and closing the clefts and also the mouth. In the higher forms many of these muscles have disappeared although some do retain their connection with the hyoid.

Visceral muscles are often divided into two sets according to their derivation, as some develop from muscles which originally ran in a transverse (circular) and others from those which ran in a longitudinal direction.

The **epibranchial** muscles, the **sub-spinals** and **interbasales** (which lie in the dorsal part of the branchial region), and the **coraco-arcuales** (in

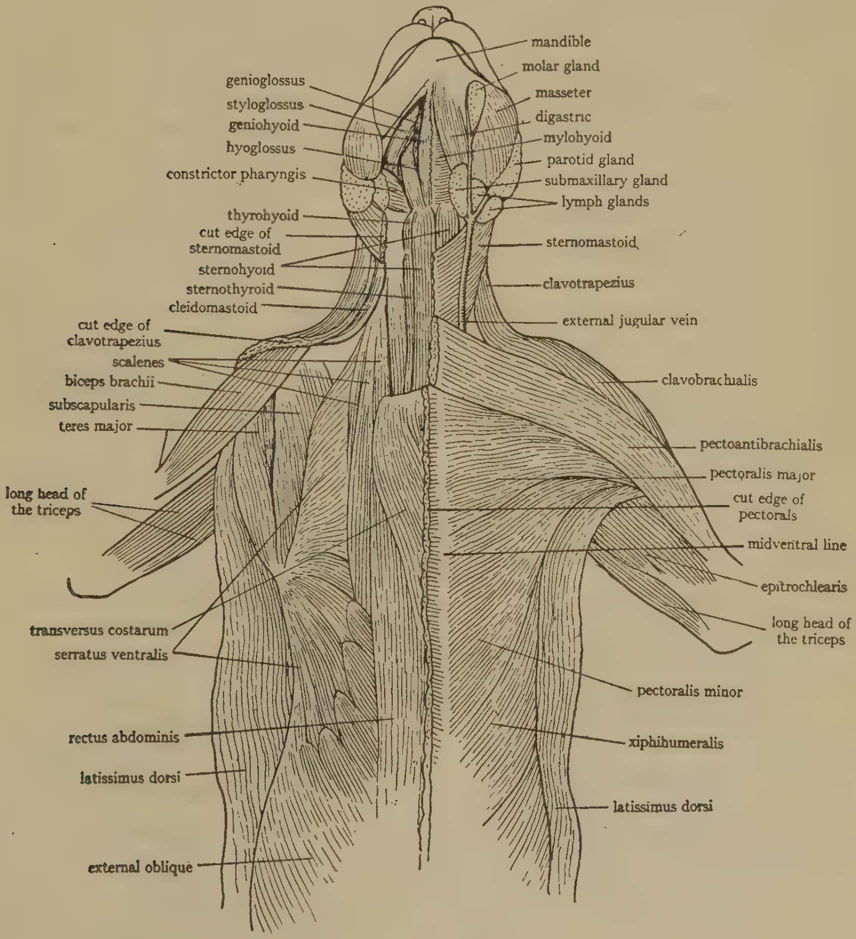

Fig. 468.

Ventral view of the anterior part of a cat to show the muscles. All dermal muscles have been removed. Superficial muscles on the right side, deeper layer of muscles on the left side, after removal of the pectoral muscles, sternomastoid, mylohyoid, and digastric. The nerves and blood vessels which cross the axilla have been omitted. The epitrochlearis is also called extensor antibrachii. From Hyman's "A Laboratory Manual for Comparative Vertebrate Anatomy," by permission of The Chicago University Press.)

the ventral or **hypobranchial** half) are derived from the circular group. The most anterior of this circular group (Figs. 467, 468) are those which open (**digastric** or **depressor mandibulae**) or close (**adductors**) the mouth, and the **mylohyoid** which extends between the two rami of the lower jaw. There are usually several adductors, known as **masseter, temporalis, pterygoideus,** accordingly as they have their origin from different parts of the skull.

The longitudinal muscles are largely confined to small slips which pass from one arch to the next. These muscles undergo considerable variation in the amphibians. In the amniotes there is also much variation but some of them are reduced on account of the loss of branchial respiration with a consequent degeneration of the parts connected with it. **The most noticeable visceral muscles, therefore, in the higher groups are those connected with the opening and closing of the mouth.**

Up to this point all muscles mentioned have had a direct connection with the skeletal system. With an increasing degree of development there develops a dermal musculature. Here the muscles are inserted directly in the skin although being derived from skeletal muscles. Primitive conditions of this kind are found in reptiles and birds and serve to move scales, scutes and feathers. This musculature attains its highest development in many of the four-footed animals, who use it to twitch the skin when insects attack them. In the primates the **platysma myoides** in the neck and head is the only muscle of the kind. It is innervated by a facial nerve which in its primitive condition came from the hyoid region. The platysma divides, giving rise to such muscles as the **orbiculares** which close the lips and eyelids, and the muscles by which one lifts the lips, nose, lids, and by which some are able to move the ears.

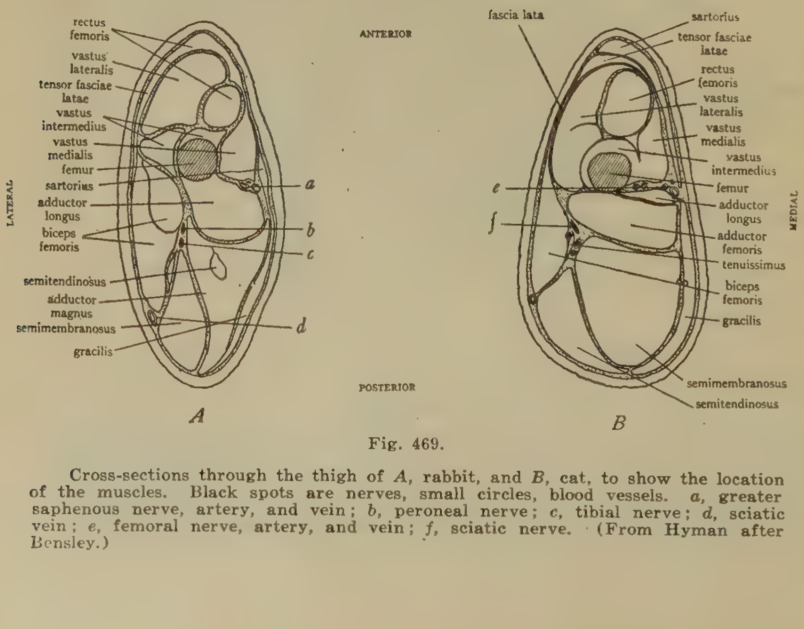

Fig. 469.

Cross-sections through the thigh of *A*, rabbit, and *B*, cat, to show the location of the muscles. Black spots are nerves, small circles, blood vessels. *a*, greater saphenous nerve, artery, and vein; *b*, peroneal nerve; *c*, tibial nerve; *d*, sciatic vein; *e*, femoral nerve, artery, and vein; *f*, sciatic nerve. (From Hyman after Bensley.)

CHAPTER LVI.

THE NERVOUS SYSTEM.

It will be remembered that the nervous system begins its career in the embryonic state by the ectoderm of the gastrula becoming flat on the dorsal surface of the embryo. This flat portion, called the **neural plate,** extends practically the entire length of the embryo. It is slightly broader at the head end than at the caudal end. The two edges of the neural plate become raised slightly and finally meet in the mid-line of the dorsal surface to form a tube. The closing of the tube begins at the head end and gradually extends backward until the tube has become completely closed. (Fig. 262).

The neural plate, consisting of ectoderm and folding as it does, causes the interior lining of the tube to be ectoderm. This is a point of considerable value in making it easier to understand various structures, such as the development of the eye. It is also well to remember here that the various **sense organs,** or special organs of sense, as they are often called, have to do with such things as touch, sound, taste and light, whose stimuli come first to the exterior part of the body. In the lower animal forms, such as the earthworms, there are no definite eyes, and yet, light rays, when thrown upon any part of the earthworm's body, cause it to move out of such light, showing that the animal is sensitive to these light rays even though there be no organ developed by which any one particular spot is specialized to receive more impressions than another part.

Now, just as the complete digestive tract develops from a straight tube by inpushings and outpushings, so the greater portion of the nervous system has developed in a similar manner from the single nerve tube that has just been discussed.

One of the explanations given as to why the nervous system develops in the way it does from the ectoderm and on the dorsal surface of the embryo, is that remote ancestors of the vertebrates may have spent their years upon the ocean-bottom, causing the ventral surface of the body to lie in contact with the ground substance and thus serve as a protection from attack, while the upper part of the body came in contact with substances and animals inimical to it. These vertebrate ancestors thus needed a sense-perception organ for protective and nutritive purposes. Interesting as this may be, it must be admitted that one of the great difficulties with which biologists have had to deal is the fact that, in the invertebrates, the nervous system lies upon the ventral surface. It is only in the higher forms that it lies upon the dorsal. Several ingenious explanations have been attempted but none is satisfactory. Students should appreciate the fact that our elaborate nervous system which controls every movement of the body, is one of the most highly and elaborately **protective systems** we could possibly possess.

The brain itself, the head-end of the nervous system, is enclosed in a remarkable bony case, while the spinal cord (the continuation of the brain, caudad), is encased within the slightly movable but nevertheless well fitted vertebrae that make up the spinal column. The brain and spinal cord combined are called the **central nervous system** so as to distinguish it from the **peripheral nervous system,** which latter consists of all those nerves arising **from** the brain and spinal cord.

As the central nervous system is composed of an infolding of the outer portion of the body, the ectoderm thus infolded into the central portion of the neural tube, becomes the **sensitive part** of the central nervous system. This **sensitive surface lines the lumen** of the neural tube, and while this condition remains in all higher forms, including man, we shall see in our study of the brain that larger or smaller masses of gray matter **may migrate** to various parts of the brain.

It will be readily understood that a nervous system of this kind, which is well protected by a bony covering, has many advantages over mere external tactile-sense spots, such as the earthworm possesses; still, to be of any value whatever, any inner sensory portion must **retain its connection with the outer portion of the body.** It is such connections which, when they have definite cells and processes that unite with the central nervous system and are grouped together, become **special sense organs.** Such nerve fibres, together with their cells, are known as **sensory nerves.** Sensory nerves must therefore carry impulses **from outer portions** to innermost regions, or in other words, from the external portions of the body **to the central nervous system.**

The object of the nervous system is primarily to inform the animal of the conditions, good and bad, in the environment, to correlate this information, and to regulate the motion so that advantage may be had of this knowledge. In those forms of animals which are segmented, that is, in which metameres appear, especially when this metamerism is in the mesothelium from which the myotomes develop into muscles, there are usually one or more pairs of **motor nerves** going to these segments because each muscle must have its own nerve supply. The motor nerves carry impulses from the central nervous system **to the muscle** or organ in which they are placed.

The close association of sensory and motor nerves in the trunk region of vertebrates has not been satisfactorily explained. In **Amphioxus** the two kinds of nerves are independent of each other throughout their course which tends to show that the vertebrate condition is not primitive.

THE SPINAL CORD.

After the neural tube has formed by a joining in the dorsal midline of the two folds of the neural plate, the cells on each side of the neural tube proliferate very rapidly while those of the roof and floor do not. This causes an outgrowth of the two sides so that a **fissure** (Fig. 470) or groove is formed on the ventral surface running the whole length of the cord. In fact, the cells on the side have already begun to proliferate before the closing of the tube. There is an ingrowth of connective tissue and blood vessels on the dorsal midline which forms a **posterior** or **dorsal septum** dividing the dorsal part of the cord into halves. The entire lining of the central canal, composed of epithelial cells, is known as **ependyma** and while no definite nervous cells can be seen, it is sensory, and remains sensory throughout its entire career.

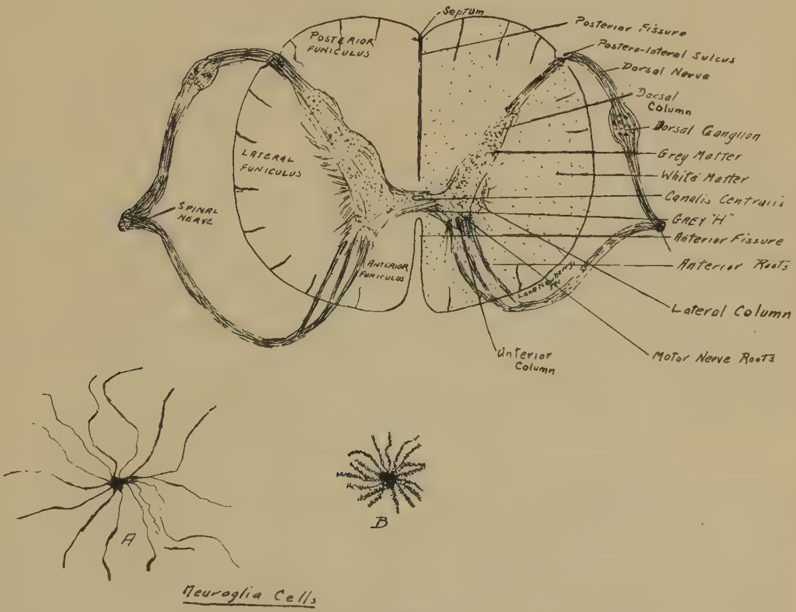

Fig. 470.

Cross section of spinal cord. *A*, "spider" cells, *B*, "mossy" cells.

The remaining cells on each side develop into two kinds of cells, one called **neuroglia** or simply **"glia" cells,** which are used to support the true nerve cells; the others form **neuroblasts** which develop true nervous tissue. This latter type of cell must develop a fibre in order to connect with other cells and with other portions of the body. These are formed by a **cytoplasmic** outgrowth from the neuroblast itself. Such processes may be several feet in length or very short. Some of the little fibres produced in this way may extend out from the cord as individual nerves, while others run longitudinally within the cord. Others run on the outside of the cord longitudinally. Those that run along the outer portion of the cord are often called the marginal layer because they form a sort of envelope of fibers for the neural cord itself. These fibers are **medulated** or covered with a white substance and this white envelope is called the **white matter** of the cord. That portion lying further toward the lumen and composed largely of **cell bodies** is what constitutes the **gray matter.**

In cross-sections of the spinal cord of a higher vertebrate there will be seen a portion looking something like the capital letter "H" with a central canal in the middle of the cross-bar. The entire substance which looks like the letter "H" is the gray matter of the cord. The dorsal upright bars of the "H" form the **posterior columns,** while the ventral uprights form the **anterior columns** of the cord. Immediately lateral to the crossbar on each side of the cord there is another column known as the **lateral column.** This latter differs to a considerable extent not only in its relation but also in its function from the dorsal and ventral column. This H-shaped gray matter really divides the white matter into **three longitudinal tracts** called **funiculi,** formerly also called columns. They are known as the **dorsal, ventral,** and **lateral funiculi.**

It will be remembered that the white matter is composed of longitudinal fibres. It is these longitudinal fibres which make up the various funiculi which connect the different parts of the central nervous system with each other. It is important to remember that these fibres are not all alike, but that those in the **dorsal funiculus** carry impulses **toward** the brain and are therefore called **ascending tracts**; while the ventral funiculus is known as the **descending tract** in that it carries fibres from the brain downward. The lateral funiculi have fibres of both kinds and carry impulses in both directions.

The fibres in each of the funiculi are again grouped into smaller bundles or **fasciculi,** each with its own name. Some of the fibres coming from the brain are distributed at different levels along the cord, while others, going to the brain, are added to the funiculi at different places. The size of the funiculi thus decreases with the distance from the brain. Some of the bundles may disappear in the more distal parts of the cord.

The spinal cord is approximately cylindrical in the higher animal forms, but in the lower it is flattened dorsoventrally, the flattening being greatest in the cyclostomes. In the lower groups there is also a difference in the shape of the gray matter, the H shape being less distinct.

The cord tapers pretty regularly in fishes, from the brain to the posterior end, but when legs have developed with an increase of musculature, the spinal cord becomes enlarged in the regions where the nerves for the limbs are given off. Casts of the spinal canal in certain fossil reptiles indicate that there was an accumulation of nervous matter near the hind legs which exceeded the brain in size.

The nerves leave the spinal cord at nearly right angles to its axis when development begins. Then there occurs an inequality in growth, the body increasing more in length than does the cord. As a result the more caudal nerves pursue a very oblique course, and in the hinder part of the spinal canal of the higher vertebrates they form a bundle of parallel nerves, the **cauda equina** (horse-tail). Often, too, another result of the unequal growth may be the drawing out of the hinder end of the cord into a slender, non-nervous thread, the **filum terminale** (Fig. 17).

Flexures (Fig. 288).

In the early stages of development, it will be remembered, the head end of the developing spinal cord bends forward at almost right angles to the main axis and this first bend is called the **primary flexure.** The second bending occurs at the most caudal end of the medulla oblongata and is called the **nuchal flexure**; it bends in the same direction as does the first or primary. The third bend is at a level with the cerebellum and is known as the **pontal flexure**; it bends in the opposite direction of the other two, thus drawing back the fore part of the entire brain to lie on top of the more rearward portion.

The three flexures just mentioned remain throughout adult life in all mammals, but even where one or more of the flexures appear in the embryonic state in vertebrates lower than mammals, it is seldom that more than one or two remain. In reptiles and birds the nuchal and pontal flexures are weakly developed and entirely obliterated in the adult.

Neuromeres (Fig 278).

There have been many interesting theories advanced in times past as to whether or not skull and brain portion of animals were merely a continued segmented portion of the spinal column and cord. There has never been any satisfactory solving of the matter, however. This much we know: that during its development the brain does show some traces of segmentation in a linear arrangement. These segments are called **neuromeres,** of which eight are well defined. Five lie in front of the ear, one corresponds to the ear in position, and two lie behind the ear.

It is from the first of these segments (though some insist there are two here) that the fore-brain arises, as well as the parts which in turn arise from it. The second becomes the mid-brain. The third lies in the region of the cerebellum. The fourth and fifth lie in the region of the more cephalic portion of the medulla oblongata where the trigeminal and facial nerves arise. From the sixth the glossopharyngeal nerve arises, while the vagus is directly connected with the remaining two.

Meninges.

In examining any brain, one finds, after the bony parts of the skull have been carefully removed, a connective tissue envelope lying close to the bone. This is called the **endorhachis,** but is really the periosteum or perichondrium of the bony parts and not a true envelope of the brain.

In the ascending groups of vertebrates we find a more complex arrangement of brain and spinal-cord-envelopes. It must be understood that what is here said of the brain-coverings proper, must also be said of the entire spinal cord.

In the fishes there is but a single covering envelope called the **meninx primativa.** The blood vessels are carried within this meninx. There is an open space between this meninx and the endorhachis called the **perimeningeal space** filled, as are all such spaces, with the **cerebrospinal fluid.** Tiny strands of tissue pass between the two connective tissue layers.

In the urodeles, and from there on upward in the various phyla, the meninx has two layers, namely the **pia mater,** which bears the blood supply and lies close to the neural cord, and the dura spinalis or dura mater. A space between these two layers is called the **subdural space,** while the perimeningeal space is then called **peridural.**

In mammals the outermost layer of the pia mater again separates from the pia proper, becoming a delicate **arachnoid layer,** and the space thus formed is called the **subarachnoid space.**

In man and some of the higher groups of animals the dura spinalis unites with the endorhachis, obliterating the subdural space, and this united sheet of covering is called the **dura mater.** This dura mater forms two strong folds in the mammals, and to a small extent in birds, and presses longitudinally into the longitudinal fissures separating the two hemispheres of the brain. It is then known as the **falx cerebri.** The other fold presses transversely between cerebrum and cerebellum forming the **tentorium.** Sometimes these folds even ossify and unite with the skull.

THE BRAIN.

The forepart of the spinal cord becomes constricted in two places transversely, forming three divisions, each being hollow in the center (Fig. 288.)

Starting with the cephalic end (Fig. 471), the first compartment thus formed is known as the **fore-brain** or **prosencephalon.** The central portion forms the **mid-brain** or **mesencephalon** while that portion extending caudally is called the **hind-brain** or **rhombencephalon.**

Cyclostomes are the only vertebrates whose brains remain in this simple three-chambered state. In all other forms there are many modifications of the primitive brain, though no matter how many modifications there may be, they all form as ingrowths or outgrowths of this primary type.

The prosencephalon divides into an **end-brain** or **telencephalon** consisting of the **cerebral hemispheres**, and the **twixt-brain** or **diencephalon** consisting of the **thalamus** and the **hypothalamus**. Each of these in turn again divides, forming the parts enumerated in the accompanying table. (Pages 840, 841).

The mesencephalon divides into **four lobes** (in mammals called **corpora quadrigemina** and in lower forms of vertebrates, where these bodies have not again divided transversely, **corpora bigemina** or optic lobes), and **cerebral peduncles.**

The rhombencephalon is made up of the **isthmus rhombencephali** (consisting of the **superior cerebellar peduncles**, the **anterior medullary velum**, the **trigonum lemnisci** and the **crura cerebri**, the isthmus itself connecting mesencephalon and rhombencephalon), the **metencephalon** (consisting of **cerebellum** and **pons**), and the **myelencephalon** or **medulla oblongata.**

THE CEREBRUM

The prosencephalon and the mesencephalon together are often called the **cerebrum.**

The greater part of the telencephalon is made up of the two **hemispheres** which are divided by a **longitudinal fissure.** This fissure is not well marked in fishes, but is very distinct in other groups of animals. The **lateral ventricles** are contained one in each hemisphere, while a part of the third ventricle (commonly called the **foramen of Monro**), (Fig. 303), lies between the two. The **corpus striatum** is a **ganglion mass** lying upon the floor of the lateral ventricle, while the **cortex** of the hemispheres is called the pallium.* The substance of the hemispheres varies to a considerable extent in the different types of animals. In fact, in the fishes it is practically all pallium, for there is merely a thin nonnervous covering to the ventricles. In reptiles and birds the **gray matter** (nerve cells) is to be found on the **ventricular surface**, while the outer surface is composed of **white matter** (fibers). In the reptiles there is the beginning of a second layer of cells a little distance from the ventricular surface. In birds this is still further increased, while in mammals there is a complete layer called the **cerebral cortex** over almost the entire surface of the hemisphere.

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*The cortex merely means an outer portion, and, in the brain, is usually composed of grey matter, while the pallium is merely the outermost covering of the hemispheres, whether composed of grey matter or not.

BRAIN TABLE

- **CEREBRUM**
  - Prosencephalon (Fore-Brain)
    - Telencephalon (End-Brain) Contains Lateral Ventricles.
      - Hemisphaerium
        - Pallium (Cortex)
          - This includes the lobes (frontal, parietal, temporal, and occipital), the Insula, the gyri, the fissures and the sulci.
        - Rhinencephalon
          - **Peripheral Region** (Anterior and posterior olfactory lobes).
          - **Central Region** (The Hippocampus and the following gyri: fornicatus, dentatus, uncinatus, intralimbicus, fasciolaris, and Andrae Retzii).
        - Stem of End-Brain
          - Corpus Striatum
            - Nucleus caudatus.
            - Nucleus lentiformis.
          - Claustrum.
          - Nucleus amygdalae.
          - Lamina terminalis.
          - Optic recess.
    - Diencephalon (Inter-Brain) Contains Third Ventricle.
      - Hypothalamus
        - Optic chiasma and tract.
        - Tuber cinereum with infundibulum and hypophysis.
        - Mammillary bodies.
      - Thalamencephalon
        - Thalamus (Anterior, medial and lateral nuclei).
        - Metathalamus (Geniculate bodies).
        - Epithalamus (Habenular region, pineal body and posterior commissure).
  - **Mesencephalon (Mid-Brain) .... Contains Cerebral, or Sylvian Aqueduct.**
    - Peduncli cerebri
      - (Connecting the optic thalamus by a mass of fibres to the central part of the brain-stem.) The peduncles are divided into a ventral segment, the **base** and a dorsal area, caled the **tegmentum**. A grayish-black substance, the **substantia nigra**, separates the parts.

	in mammals. (Corpora **bigemina** in Lower Vertebrates)		colliculi, the posterior ones being known as **posterior or inferior colliculi. The colliculi extend** laterad forming an arm **and called respectively the brachium quadrigeminum superior** and **inferior.)**
Rhombencephalon (Hind Brain) Contains Fourth Ventricle.	Isthmus rhombencephali		The **superior cerebellar peduncles** or **crura cerebelli ad cerebrum.** (Two flattened cylindrical columns extending from cerebellum to the quadrigeminal plate.) **Velum medullare anterius.** (A thin medullary sheet stretching between the superior cerebellar peduncles.) **Trigonum lemnisci.** (A grayish triangular field.)
	Metencephalon	Cerebellum	Medial portion (known as the worm). Lateral portions (known as cerebellar hemispheres). There are three lobes in each hemisphere corresponding to definite segments in the worm. (Lobus **superior, posterior** and **inferior.)**
		Pons	(The ventral side forms the **brachium pontis** or **middle cerebellar peduncle** connecting with the cerebellum dorsad. The brachium is made up of three **fasciculi:** superior, inferior and medius.)
	Myelencephalon (Medulla oblongata)		Ventral side (Pyramids and Olives.) Dorsal side (Rhomboidal fossa.)

As the brain grows in a bony case, it follows that as soon as the brain has grown longitudinally the full length of this case, it must bend in the various directions the case lays down for it. Therefore, in the mammals, the posterior end of the hemispheres grow dorsally and downward, and then forward again until that portion of the hemisphere which was originally most posterior has now grown forward until it reaches, or at least touches, the olfactory region. The part growing downward and then forward grows over a part of the side-wall of the hemispheres which por-

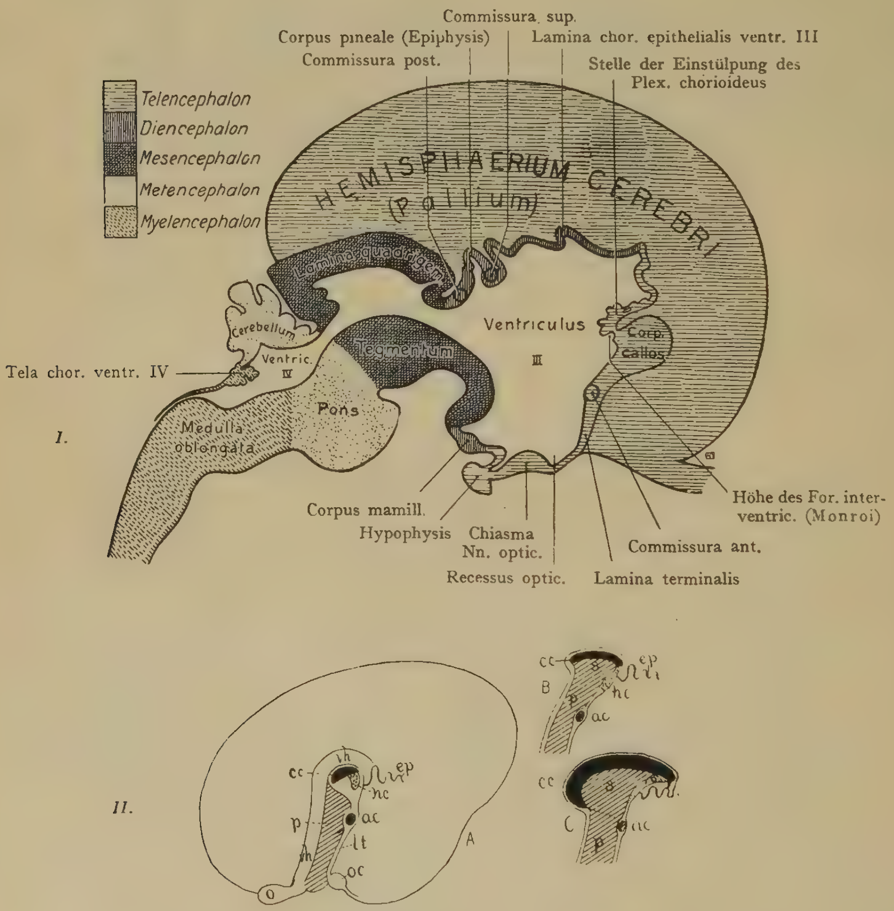


Fig. 471.

I, Schematic median section of brain of a four month human foetus to show the various changes caused by the developing hemisphere. (From Corning after Burckhardt.)

II, Diagram of the development of the corpus callosum and septum pellucidum in man. *A* shows the hemisphere in outline. *ac*, anterior commissure; *cc*, corpus callosum; *ep*, epithelial roof of the third ventricle; *hc*, hippocampal commissure; *lt*, lamina terminalis; *o*, olfactory lobe; *oc*, optic chiasma; *p*, paraterminal body; *s*, septum pellucidum; *vh*, vestigial precallosal and supracallosal hippocampus. (From Kingsley after G. Elliott Smith.)

tions of the side-wall thus form a little island in the depths of the longitudinal fissure. This island is called the **insula** (of Reil).

The bending itself of the downward and forward growing parts has caused a deep transverse fissure in each hemisphere known as the **lateral cerebral fissure** or **fissure of Sylvius.**

All higher forms of mammals have the brain substance thrown into many folds or **convolutions** known as **gyri** (Fig. 473).

The deeper grooves separating the gyri are called **fissures,** while the lesser grooves are known as **sulci.** This folding permits a great amount of cortex or gray matter to be provided for; for, it will be noted that not only do the **tops** of each convolution form cortex, but also the **entire sides of every sulcus.**

The hemispheres are divided into various lobes: **frontal, parietal, temporal** and **occipital.** The two hemispheres are connected by various **commissures,** which likewise must be studied in the actual brain and compared with the diagram.

Following are the chief commissures (Fig. 471):

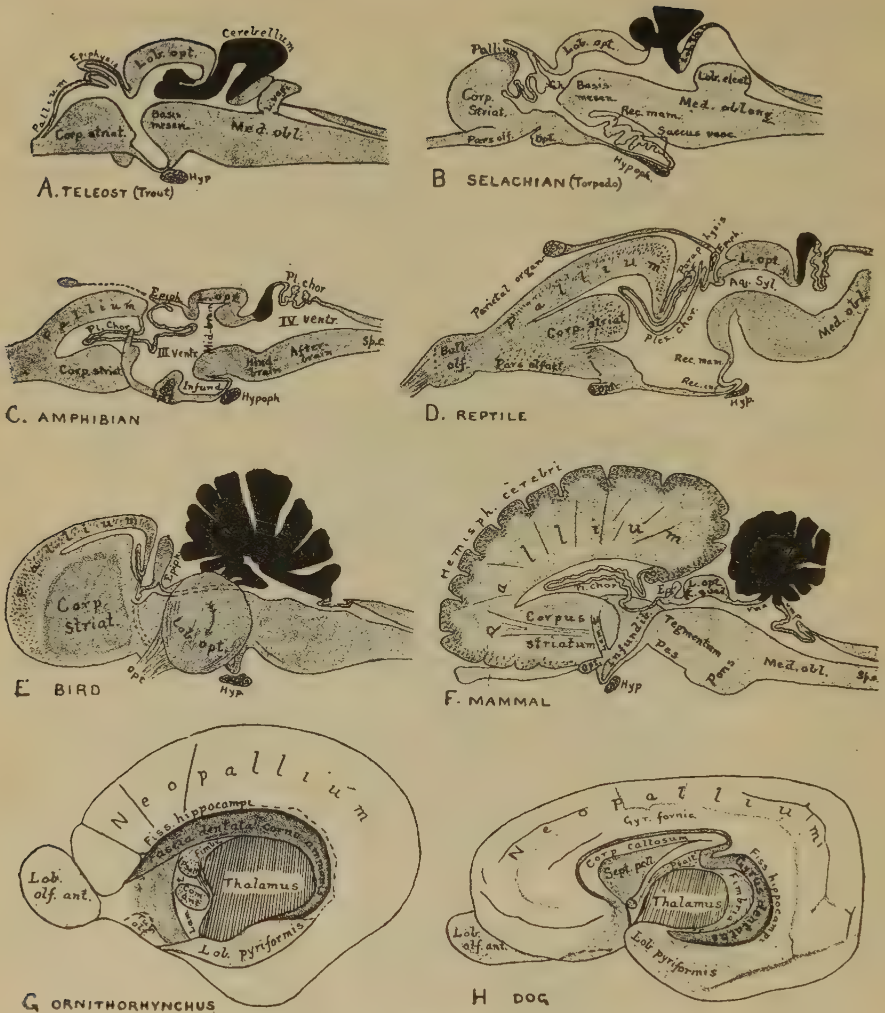
Anterior commissure, in all vertebrates.

Pallial commissure, dorsal to the anterior. This appears in vertebrates from the amphibians upward.

Corpus callosum (Fig. 471), and

Hippocampal commissure. These last two are a variation in the higher mammals of the pallial commissures in the lower. The corpus callosum is developed to a greater extent in man than in other animals (Fig. 472). This is explained by the fact that in no other animal does mentality reach so high a state of development as in man, and, because the cerebral hemispheres are the seat of mentality, it follows that much greater connection between the cortex of the two hemispheres is needed in man than in other animals. There is a thin translucent membrane between the body of the corpus callosum and the **fornix** known as the **septum pellucidum,** which leaves a slight cavity between the two septa of each side. Formerly this cavity was called the **fifth ventricle.** It has no connection whatever with any of the true ventricles.

Two tracts of nervous matter run back on the medial side of either hemisphere, from the olfactory lobe to the hinder end of the cerebrum. One of these is the **hippocampus,** which passes dorsad, and the other is the olfactory tract, which goes ventral to the foramen of Monro. These two and the associated olfactory substances make up practically all of the so-called **archipallium** in the lower vertebrates, for in these the whole cerebrum really is accessory to the sense of smell. In mammals, and possibly as low as the reptiles, a part has been added to receive impressions from other somatic senses. This is the **neopallium** which has grown out lateral to the hippocampus and is especially large in the higher mammals. In man it forms by far the greater part of the cerebrum. Its great development forces the olfactory parts to the medial and lower



A. TELEOST (Trout)

B SELACHIAN (Torpedo)

C. AMPHIBIAN

D. REPTILE

E BIRD

F. MAMMAL

G ORNITHORHYNCHUS

H DOG

Fig. 472.

Comparison of Various Types of Brains. A-F (*Edinger*) are sagittal sections showing structures lying in the median line and also paired structures (e.g., pallium) lying to one side of the median line. The cerebellum is black. It is doubtful whether the membranous roof in A indicated as pallium is strictly homologous with that structure in other forms. In B, *Pallium* indicates prepallial structures, *Aq.Syl.*, Aquæductus Sylvii; *Basis mesen.*, basis mesencephali; *Bulb. olf.*, bulbus olfactorius; *Corp. striat.*, corpus striatum; *Epiph.*, epiphysis; *G.h.*, ganglion habenulæ; *Hyp.*, hypophysis; *Infund.*, infundibulum; *Lam.t.*, lamina terminalis; *Lob. elect.*, lobus electricus; *L.vagi*, lobus vagi; *L.opt.*, mid-brain roof; *Med.obl.*, medulla oblongata; *Opt.*, optic nerve; *Pl.chor.*, plexus chorioideus; *Rec.inf.*, recessus infundibuli; *Rec.mam.*, recessus mammillaris; *Saccus vasc.*, saccus vasculosus; *Sp.c.*, spinal cord; *vent.*, ventricle; *v.m.a.*, velum medullare anterius; *v.m.p.*, velum medullare posterius. G and H show the mesial surface of the cerebral hemispheres in a low (G) and high (H) Mammal. *G Elliott Smith, Edinger,* slightly modified. The exposed gray matter of the olfactory regions is shaded, the darker shade indicating the archipallium (preterminal area and hippocampal formation), the lighter shade indicating the rhinencephalon, which consists of the anterior and the posterior (principally pyriform) olfactory lobes, and a central region made up of the hippocampus and the following gyri: fornicatus, dentatus, uncinatus, introlimbicus, fasciolaris, and Andrae Retzii.

surfaces so that they are exposed to view only by dissection. A part of the original hippocampus is then vestigial.

"Beginning in the amphibia and reappearing in the reptiles is a tract of fibers on either side, which connects the posterior part of the cerebrum (where the hippocampus ends) with the hypothalmus. In the mammals, by the flexure of the cerebrum, this same band of fibers, here called the **fornix,** is obliged to take a circuitous course. Starting at the hippocampus on the medial side of the temporal lobe, the fornix runs up, then forward, below the corpus callosum, and then down, in front of the interventricular foramen to end in a protuberance, the **corpus mammillare,** on the floor of the hypothalmic region."

Headward, on the dorsal side, the walls become somewhat thickened, bulging out into a pair of prominences known as the **optic lobes** or **corpora bigemina** in the lower forms of animals, while in the mammals there are two such pairs of lobes which are therefore called **corpora quadrigemina** (Fig. 473). The roof of this region remains comparatively thin, but the floor becomes somewhat thicker and forms the **cerebral peduncle.** Connecting the mid-brain with the hind-brain is a short constricted area known as the **isthmus.** From here running caudad along each lateral wall there is often a groove (seldom, if ever, seen in the adult) called the **limiting sulcus** or the **sulcus of Monro.** This naturally divides the brain and spinal cord from here to the tail-end into a dorsal and a ventral half, a fact that is of considerable importance, because the entire **dorsal area is sensory** while the **ventral is motor in character.** Further, in the study of the central nervous system's development it is the dorsal portion in which most of the changes come, comparatively few developing on the ventral side.

The hind-brain is again divided. The part lying cephalad develops into the **cerebellum** or balancing brain (organ of coördination), while the caudal end tapers rather gradually and is known as the **myelencephalon** or **medulla oblongata.** The cavity in the hind-brain, most of which is located within the medulla, is known as the **fourth ventricle,** while the small lumen which connects the third and fourth ventricle is called the **aqueductus cerebri** or the **aqueduct of Sylvius** (Fig. 282).

It will, therefore, be noticed that from the earlier three compartments of the head end of the brain and spinal cord there have developed five brain divisions with four ventricles. All the ventricles form a continuous open space throughout the entire central nervous system.

The roof plate in the region of the cerebellum, which originally was quite thick, forces the most cephalic portion of the two dorsal zones far apart, so that they then become quite thin and broad, whereas the floor plate becomes greatly thickened and constitutes the **pyramids** which pass in front into the cerebral peduncles.

A comprehensive study of the brain is a tedious and difficult task and requires a very thorough going over, and remembering the main

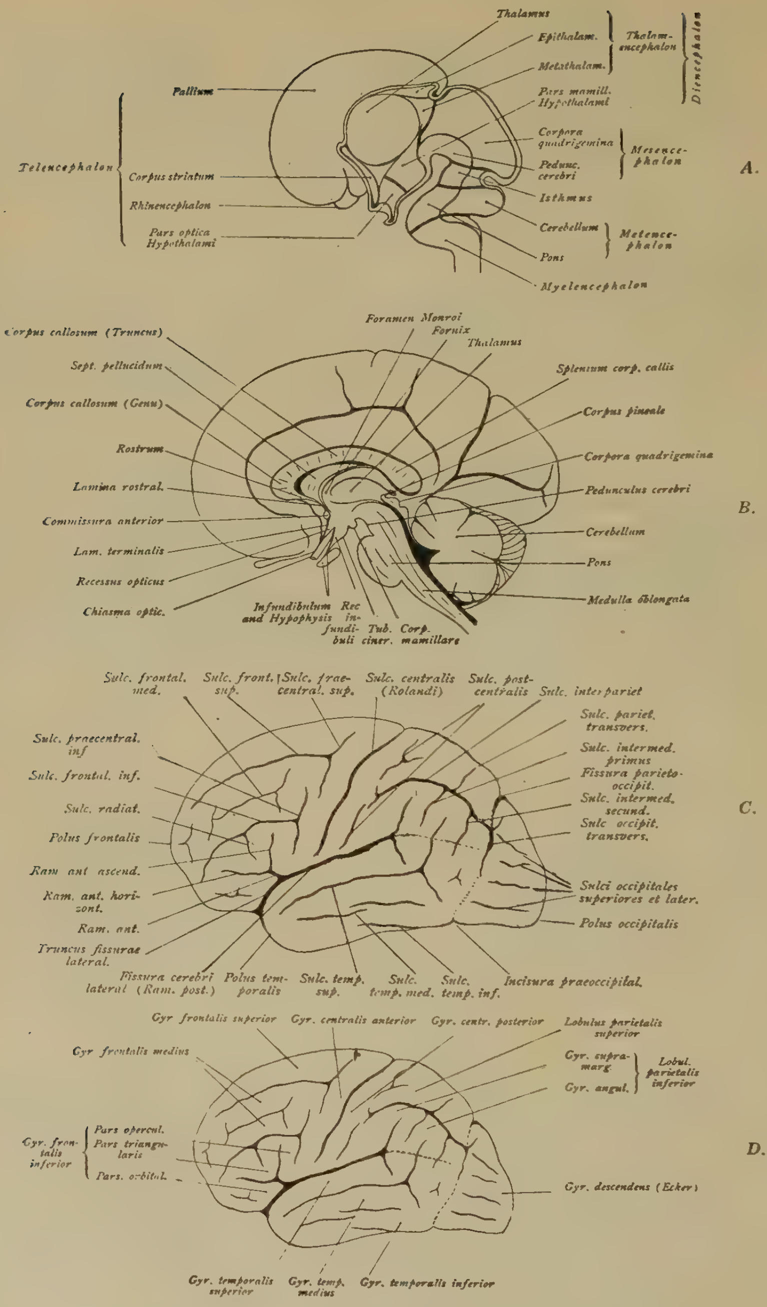


Fig. 473.

A, Diagram to show development of five secondary brain vesicles. (After His.) *B*, Median sagittal section through brain of man. *C* and *D*, dorso-lateral cerebral surfaces. *C* to show fissures and sulci, and *D* to show gyri. (After Villiger.)

points in the histology, general anatomy, and physiology of the frog. And the task is made the more difficult on account of all the early studies having been made upon the human brain before our better stains made it possible to understand the finer structure of nerve cells and fibers. The result is that the names of the various parts of the brain have been derived from fanciful resemblances, often very confusing.

We shall attempt to study the entire central nervous system in terms of **function** rather than in terms of **structure**, and the latter only in its development, as then, and then only, are we able to place a valid interpretation upon our findings.

Following are several terms without which no progress in this study can be made:

A **center** is any group of nerve-cells which performs a single function. (This does not imply, however, that **all** of this particular function is located in this one center alone. There may be several, or many, performing similar functions.)

It is these centers which form a sort of switch-board for the redistribution of various nervous impulses.

Afferent fibers are those which conduct toward the centers.

Efferent fibers are those which conduct away from a center.

Peripheral nerves (those running from and toward the central system) are naturally **mixed nerves** in that they carry both afferent and efferent fibers.

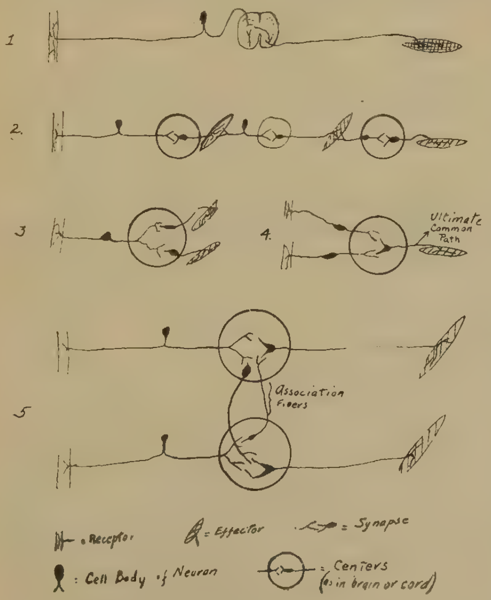


Fig. 474.
Five types of reflex arcs.

Inhibitory fibers are those which check an action.

White matter (substantia alba) is that portion where the nerve fibers are covered with white myelin sheaths.

Gray matter (substantia grisea) is that portion where there is a mass of nerve-cell-bodies uncovered with myelin sheaths.

Brain nuclei are the gray centers **within** the brain, which are divided in turn into:

Primary centers which are those directly connected with the peripheral nerves, either as **terminal nuclei** of afferent fibers or as **nuclei of origin** of efferent fibers, and

Correlation centers, which are those in which the impulse received is redistributed after meeting with other impulses at a common center.

Figure 474 shows the five ways in which impulses are and may be distributed.

Ganglia are those centers similar to brain nuclei which lie **outside** the brain, although some books still use this term interchangeably with **brain nuclei.**

Brain stem (also called **segmental apparatus,** because it is supposed that the primitive type of brain consisted of a mere tube of nerve-cells with which the peripheral nerves were connected, a pair from each segment, similar to the spinal cord of the higher forms now), is that portion of the cephalic end of the central nervous system upon which the enormous cerebral and cerebellar hemispheres develop in all higher forms. These latter are then called the **suprasegmental apparatus.**

Cerebrum consists of fore-brain and mid-brain, the most cephalic part of which develops into the cerebral hemispheres which are again divided as seen in the table.

The **pallium** in the highest animal forms is the **cerebral cortex** or mantle (Fig. 472), but in the lower forms such as the fish, in which the entire hemispheres are a part of its olfactory apparatus, the pallium consists of this olfactory apparatus and the two tracts of nervous matter connecting the olfactory lobe with the hinder portion of the cerebrum. One of these tracts, the **hippocampus,** passes dorsal, and the other, the **olfactory tract,** passes ventral to the foramen of Monro. They lie on the medial side of each hemisphere.

Archipallium is the word now used to a considerable extent for the pallium in the lower vertebrates where this mantle is concerned practically only with the olfactory apparatus.

Neopallium has therefore come into existence as a term to designate the pallium of the vertebrates whose brain is not governed entirely by its olfactory apparatus, but where impulses from the general somatic senses may be adjusted and be redistributed in a great correlation region —**the cerebral cortex.** In the table the pallium corresponds to this neopallium which has grown out lateral to the hippocampus.

Rhinencephalon (nose-brain), the entire olfactory apparatus divides into peripheral and central regions as in the table.

Corpus Striatum (Figs. 472, 473). This is the name given to the entire mass of large nerve cells which connect the brain-stem with the cerebral hemispheres. It is also called the **basal ganglion.** It will be noted that the corpus striatum thus forms the main portion of the stem **of the end brain.** It is called striated because it consists of masses of gray matter separated by sheets of white matter, thus making it appear striated.

In the lower forms of vertebrates (Fig. 473) some have this body fairly well developed even though there be no cortex, while in reptiles and birds in which there is a small amount of cortex it is quite highly developed. In these animals the corpus striatum seems to be a reflex center of a higher order than the thalamus.

There is doubt as to the exact function of the corpus striatum. Ramon y Cajal thinks that in mammals, at least, this body functions as a reinforcement center of the descending motor impulses coming from the cortex, as these fibers give off collateral branches when passing through the corpus striatum, while the striatum itself sends important descending tracts into the thalamus and cerebral peduncle.

The white matter consists of fibers that pass between the cortex and deep parts of the brain-stem which have no functional connection with the striatum itself. These are called **projection-fibers,** and are partly ascending and descending fibers which pass between the thalamus and the cortex, and partly descending motor projection-fibers of the cortico-spinal or pyramidal tract, cortico-bulbar tract, and cortico-pontine tracts

The gray matter of the corpus striatum forms the two nuclei named after their shape the **caudate** and the **lentiform nucleus** (Fig. 475). Most of the projection-fibers pass between these two nuclei in a wide band of white matter which is called the **internal capsule.** These same fibers radiating from the internal capsule toward the capsule are called the **corona radiata.**

The **external capsule** is formed of a thinner sheet of fibers external to the lentiform nucleus.

As many cases of apoplexies and other cerebral diseases cause hemorrhage and other injuries in the internal capsule, there destroying some of the fibers, the study of the exact arrangement of sensory and motor projection fibers within the internal capsule is of great clinical importance.

Claustrum is the name given to the thin band of gray matter lying between the external capsule and the cortex of the insula (Fig. 475, B).

Nucleus amygdalae is a small mass of sub-cortical gray matter under the tip of the temporal lobe. It forms part of the **nucleus olfactorius lateralis.**

Thalamus (Fig. 475). The middle and larger subdivision of the diencephalon, sometimes even applied to the entire diencephalon and called the **optic thalamus.**

As **all** nervous impulses which reach the brain cortex, except those that come from the olfactory organs, pass through the thalamus, this organ serves as a sort of vestibule for the cortex and probably also as a great relay station for the incoming and outgoing nerves.

It is to be remembered that the optic fibers which occupy the thalamus take up much of that organ, but **it should not be called the optic thalamus** because **all** fibers to and from the cortex, regardless of whether coming from the eye or not, pass through the thalamus.

Two parts of the thalamus are to be noted. The ventral portion contains chiefly motor coördination centers. In man this position is not

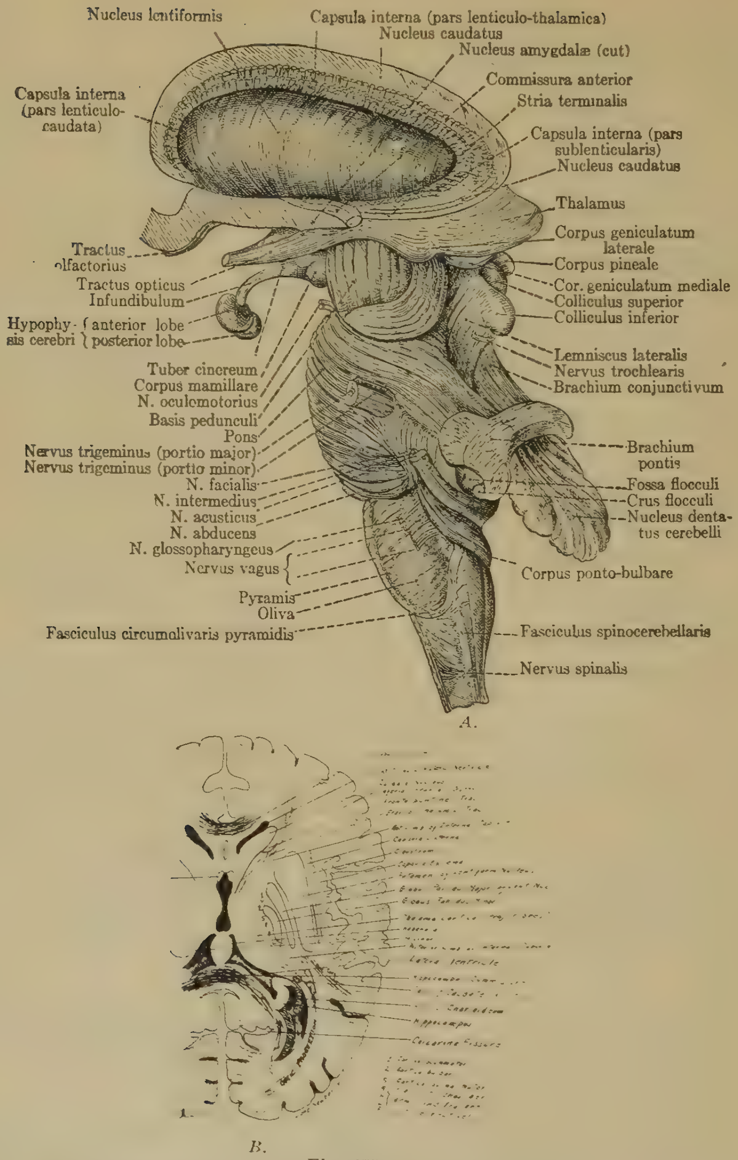


Fig. 475.

A, Left lateral aspect of a human brain from which the cerebral hemisphere (with the exception of the corpus striatum, the olfactory bulb and tract, and a small portion of the cortex adjacent to the latter) and the cerebellum (excepting its nucleus dentatus) have been removed. The brain stem (segmental apparatus; palæëncephalon) includes everything here shown with the exception of the strip of cortex above the tractus olfactorius and the nucleus dentatus. Within its substance, however, are certain cortical dependencies (absent in the lowest vertebrates), which have been developed to facilitate communication between the brain stem and the cerebral cortex. The chief of these are found in the thalamus, basis pedunculi, and pons. Compare this with the side view of an intact brain, Figure 473. (From Herrick after Cunningham.)

B, Horizontal section of human cerebral hemispheres. 1, 2, *A*, *H*, *L*, *F*, etc., Fiber systems.

well developed and is there called the **subthalamus,** which is often confused with the **hypothalamus.**

The dorsal portion of the thalamus is again divided into two portions:

(1) The **primitive sensory reflex centers,** principally in the medial group of thalamic nuclei.

(2) The regular cortical vestibule which forms the **lateral nuclei.** These lateral nuclei are sometimes called the new thalamus **(neothalamus)** to distinguish them from all other portions of the thalamus, which other portions are then called the old thalamus **(palaeothalamus).**

In man the new thalamus makes up by far the greater portion of that organ. This portion includes "the lateral, ventral, and posterior nuclei (for general cutaneous and deep sensibility) receiving the spinal, trigeminal, and medial lemnisci; the lateral geniculate body and pulvinar (visual sensibility) receiving the optic tracts; the medial geniculate body (auditory sensibility) receiving the lateral or acoustic lemniscus."

It will be noted that Professor Herrick, from whom this quotation is taken, considers the two geniculate bodies as a part of the thalamus, whereas our table calls them the metathalamus. The student will see that all these parts are most intimately connected, and classification is bound to be arbitrary no matter what pains may be taken to make such classification as scientific as possible.

All the lateral nuclei are connected with the cerebral cortex by important systems of fibers running both to and from the cerebral cortex. The fibers themselves are called sensory projection fibers and all of them pass through or near the internal capsule of the corpus striatum.

While these lateral nuclei receive the impulses from the somatic sensory fibers as well as the deeper sensibility impulses (such as touch, temperature, pain, general proprioceptive sensibility, spatial localization, etc., termed as a whole the somesthetic group), this latter group is probably separately represented in the thalamus although we have not yet the evidence to demonstrate it.

Each of the chief functional regions in the thalamus is connected with a specific region in the cerebral cortex by its own projection fibers, the tracts being known as **radiations.** For example, there are optic radiations, auditory radiations, somesthetic radiations, etc.

The old thalamus, which comprises the more medial thalamic centers found in lower forms, has little or no cerebral cortex, such as fish, and seems to retain its function in higher vertebrates. In other words, some "awareness" of what is going on is carried by these medial centers, so that the cerebral cortex is not absolutely necessary for the animal to be aware of its own action or reaction. This means that the cerebral cortex is not necessary for **all,** though it undoubtedly is for most conscious purposes.

Professor Herrick says: "The thalamus can act independently of the cortex in the case of painful sensibility and the entire series of pleasurable and painful qualities; for the thalamic centers when isolated from their cortical connections are found to be concerned mainly with affective experience, and destructive lesions which involve the cortex alone do not disturb the painful and affective qualities of sensation."

Hypothalamus. That portion lying immediately beneath the thalamus. A small portion of the primitive neural tube to which the hemispheres are attached has remained in a primitive state, not changing or having any ingrowths or outgrowths. This unchanged portion is called the **pars optica hypothalami,** and, as will be noticed by the table, is a part of the end-brain and not the diencephalon. The hypothalamus is an important correlation center for olfactory and various visual impulses, including probably the sense of taste.

Tuber cinereum is the gray eminence forming the ventral portion of the hypothalamus.

Infundibulum is a funnel-shaped extension of the third ventricle passing through the hypothalamus to the end of the hypophysis (pituitary body or gland which lies in the sella turcica).

Mammillary bodies are a pair of eminences at the posterior end of the tuber cinereum. These bodies are olfactory centers.

Metathalamus. The posterior part of the thalamus consists of the **geniculate bodies.** The **lateral** or **external** one is a **visual** center in the thalamus and the **medial** or **internal** body is an auditory center.

Epithalamus. This is formed by the membranous choroid plexus which forms the roof of the third ventricle, the habenula, and the stria medullaris, a fiber-tract which connects the olfactory centers of habenula and cerebral hemisphere. The habenula itself is a center for the correlation of olfactory sensory impulses with the various somatic sensory centers of the dorsal part of the thalamus. The pineal body, in a very few lower vertebrates, is a sense organ, being called a "parietal eye" (Fig. 476). In the higher forms this sensory function has been lost, though it is now supposed to be an organ of internal secretion.

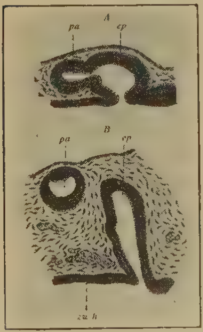


Fig. 476.

Anlage of the epiphysis (pineal gland) and parietal organ in the lizard *Iguana*. *A* in a 9 day embryo, and *B* in an 18 day embryo. Longitudinal section. *cp*, epiphysis; *pa*, parietal organ; *zw h.*, wall of the ventricle in the twixt-brain. (After von Klinkowström.)

TELENCEPHALON

In all comparative studies of animals one must observe lower forms in order that the simpler arrangement there found may furnish an understanding of the more complex adjustment found in the higher forms, as these latter, usually, possess parts that the lower forms possess, plus something additional.

In the study of the nervous system the dogfish is a good laboratory example with which to work. It has no cerebral cortex developed into immense hemispheres, as in man, and which make it so difficult to study the underlying parts and note their relationship (Figs. 477, 478).

There is a regular system of small sensory canals widely distributed in fishes containing sense-organs slightly similar to those in the semicircular canals of the internal ear. Their functions are supposed to be somewhat between that of organs of touch in the skin and those of equilibrium of the internal ear. The water vibrations of slow frequency probably make it possible for the animal thus to orient itself. Their innervation comes from the VII, IX, and X pairs of cranial nerves. The sensory canals just mentioned are called **lateral line organs** (Fig. 479) and are absent in higher vertebrates.

If Figure 480 be studied carefully it will be seen that there is a quite definite area or center for each group of impressions.

The **acoustisco-lateral** area is the terminal center of the lateral line nerves as well as the acoustic nerve (VIII pair).

The general cutaneous area receives impressions from the remaining general exterior of the body.

The nerves from the viscera (that is, from the gills, stomach, etc.) enter a visceral area.

The eye is connected with the optic lobe.

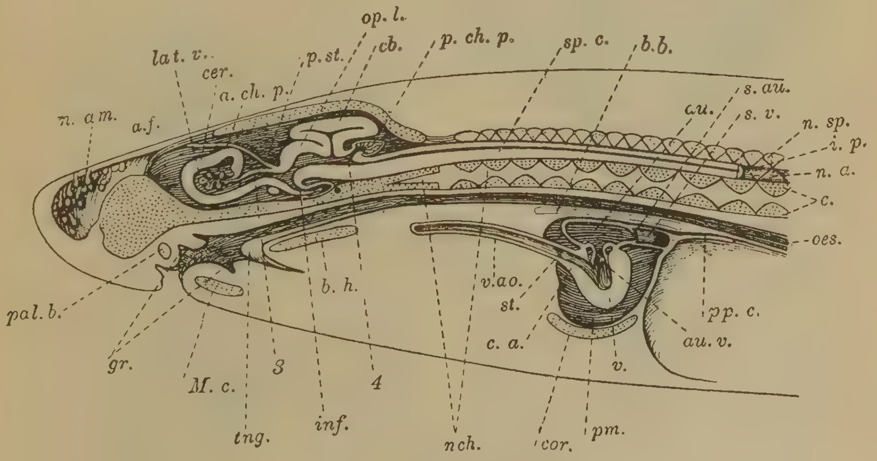


Fig. 477.

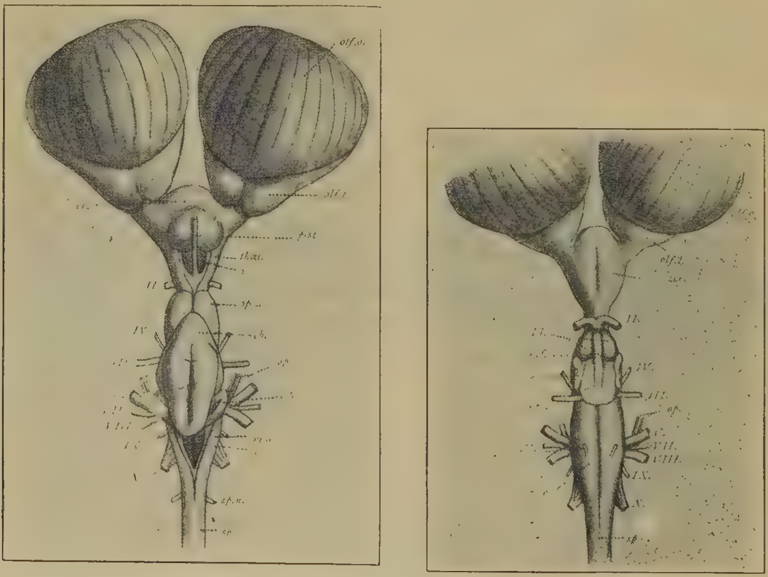
A semi-diagrammatic drawing of a longitudinal section through a dogfish, passing slightly to the right of the middle line. *a.ch.p.*, anterior choroid plexus; *a.f.*, anterior fontanelle; *au.*, auricle; *au.v.*, auriculo-ventricular opening and valve; *b.b.*, basibranchial cartilage; *b.h.*, basihyal cartilage; *c.*, centrum; *c.a.*, conus arteriosus; *cb.*, cerebellum; *cer.*, cerebrum; *cor.*, coracoid region of the pectoral girdle; *gr.*, grooves in which the teeth are formed; *i.p.*, intercalary plate; *inf.*, infundibulum; *lat.v.*, lateral ventricle; *M.c.*, Meckel's cartilage; *n.a.*, neural arch; *n.am.*, ampullary sense organs; *n.sp.*, neural spine; *nch.*, notochord; *oes.*, œsophagus; *op.l.*, optic lobe; *p.ch.p.*, posterior choroid plexus; *p.st.*, pineal stalk; *pal.b.*, palatine bar; *pm.*, pericardium; *pp.c.*, pericardio-peritoneal canal; *s.au.*, sinu-auricular opening; *s.v.*, sinus venosus; *sp.c.*, spinal cord; *st.*, semilunar valves; *tng.*, tongue; *v.*, ventricle; *v.ao.*, ventral aorta; 3, third ventricle; 4, fourth ventricle. (From Borradaile.)

The nose connects with the olfactory bulb and hemisphere. (Some writers have considered the olfactory hemisphere an actual portion of the brain equivalent to the cerebral hemisphere in man. These olfactory hemispheres are, however, only **portions** of the olfactory apparatus.)

The important point is to note that **definite brain regions** are set aside for sensory impressions, and to notice that they are all on the **dorsal surface** (except a part of the olfactory centers).

These regions which Professor Herrick understandably calls "nose brains," "eye brains," "ear brains," "visceral brains," "skin brains," etc., show the simplest type of the pattern of **functional localization** of **primary reflex centers.** That is, all these special "brains" or **centers show** that practically all of the parts of the brain (except the cerebellum) **have** a very definite connection with some particular peripheral organs.

This means that this type of simple brain is concerned, in so far as we can tell (with the exception of the cerebellum), only with simple reflex action, there being no large centers for the higher type of adjustment found in the higher vertebrate brains. However, in the higher vertebrates, even including man, there is this same type of simple con-



A. *B.*

Fig. 478.

A, The brain of the dogfish, seen from above. *cb.*, cerebellum; *cer.*, cerebrum; *m.o.*, medulla oblongata; *olf.l.*, olfactory lobe; *olf.o.*, olfactory organ; *op.*, ophthalmic branches of fifth and seventh nerves; *op.l.*, optic lobes; *p.st.*, pineal stalk; *r.b.*, restiform body; *sp.c.*, spinal cord; *sp.n.*, spinal nerve; *thal.*, thalamencephalon; 3, 4, third and fourth ventricles; *II.-V.*, *VII.-X.*, cranial nerves.

B, The brain of a dogfish, in ventral view. *cer.*, cerebrum; *inf.*, return limb of infundibulum, sometimes regarded as the pituitary body; *l.i.*, lobi inferiores; *m.o.*, medulla oblongata; *olf.l.*, olfactory lobe; *olf.o.*, olfactory organ; *op.*, ophthalmic branches of fifth and seventh nerves; *sp.c.*, spinal cord; *s.v.*, lateral lobe of saccus vasculosus; *s.v'.*, median lobe of the same; *II.-X.*, cranial nerves. (From Borradaile.)

nection also, but it is obscured by the greatly enlarged correlation centers of which the cerebral cortex is the most important. The **distinct** course in neurology given in the schools deals largely and primarily with the histological structure and function of this cortex.

Because the cerebral cortex is found only in the higher forms of vertebrates and, therefore, is supposed to have developed later in the evolutionary scale than the simpler type such as the fish displays, it has been called the **neencephalon** in contradistinction to the fish type of brain which is then known as the old-brain or **palaeencephalon.**

Another point to note is that the "ear brain," the "skin brain," and the "visceral brain" are all contained **in the rhombencephalon.** In fact, the "stem" of the rhombencephalon (also called the segmental portion) is made up of these sensory "brains" and their corresponding motor centers.

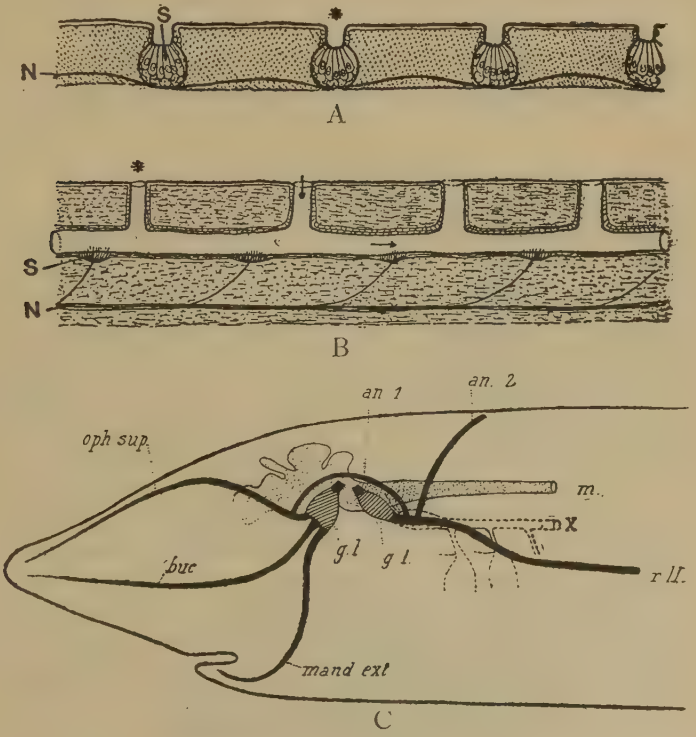


Fig. 479.

A and *B*, Schematic diagrams of sections of the skin. The sections pass through the lateral line organs. *A*, of a Teleost, *B*, of a dogfish. *N*, lateral line nerve; *S*, sensory nerve ending; the asterisk shows the cutaneous orifice; the arrows indicate the direction of the stimulus.

C, Lateral line nerve of a fish. *an1*, anastomosis between the anterior and posterior portions of the lateral nerve; *an2*, transverse anastomosis between the right and left lateral nerve; *buc.*, buccal branch of lateral nerve; *g.l.*, lateral nerve ganglion; *mand.ex.*, mandibular branch of lateral nerve; *m.*, spinal cord; *oph.sup.*, superficial ophthalmic branch of lateral nerve; *r.ll.*, branch which follows the lateral line *X*, *X* cranial nerve (dotted) to show partial fusion with lateral nerve. (From Vialleton, *A* and *B* after Dean.)

In the higher forms this is also true, and the cerebellum (in man, the pons also in a sense) are suprasegmental extensions.

In both lower and higher forms the "eye brain" includes the **retina** of the eye, the **optic nerve,** and a **part of the roof of the midbrain.** In fish only a few fibers from the optic nerve pass to the thalamus, but in the higher forms the number of fibers to this portion are many, in fact so many, that the entire thalamus, as stated, is often called the "optic thalamus."

In the fish there are no true cerebral hemispheres, the seemingly similar organs are **hemispheres of the olfactory tract** (with the exception of the very small "somatic area" which becomes the corpus striatum and cerebral cortex in the higher forms. The olfactory apparatus of the fish also embraces the entire epithalamus and hypothalamus.

It follows from all that has been said, that no nervous impulses can enter the cortex without passing through the reflex centers of the brain-stem first. The brain-stem therefore must have all the fibers lying within it which are to carry such impulses. The suprasegmental portions are therefore **correlation, coördination,** and **readjustment centers.**

DIENCEPHALON

The twixt-brain or inter-brain lies directly in front of the posterior commissure. Still further to the front it is bounded by the **velum transversum above** and the **lamina terminalis below** (Fig. 282, A, C). The cavity in the center is a portion of the third ventricle which extends to the **optic chiasma.** The fiber tracts running from the cerebral hemisphere backward pass into the side walls. Those lying in the dorsal region go through the **thalamus** (   ) where there is a large nerve center. The ventral tracts are the cerebral peduncles already mentioned. Directly above and in front of the thalamus is the **epithalamus** which also contains a nerve center known as the **habenula** (   ). The **hypothalamus,** lying as its name implies below the thalamus, consists of the **tuber cinereum** in front and the **mammillary** bodies behind. Both the epithalamus and the hypothalamus bear a relation to the sense of smell, and are, therefore, developed to a greater extent in all lower animals in which this sense is highly developed. Directly behind the velum transversum is the **superior** or **habenular commissure.**

EPIPHYSIAL STRUCTURES

It is customary to call various parts developed in the roof plate of the primitive fore-brain **epiphysial structures** (Fig. 202). Just where the cerebral hemispheres and the twixt-brain meet there is a little fold of epithelium, already mentioned, called the **velum transversum** hanging from the roof of the cerebrum. Directly in front of this is a little chorioid plexus that secretes a fluid. This is called the **paraphysis.** The other epiphysial structures belong to the twixt-brain and consist of a **parietal organ** and the **pineal gland** (Fig. 476). Both of these arise from the roof of the twixt-brain between the habenular ganglion and the posterior commissure where twixt and mid-brains meet. Sometimes they develop as a single outgrowth and sometimes as distinct structures. The more anterior of the two is the parietal organ or eye. The posterior is the pineal gland, also known as the **epiphysis.** These two organs, although varying in the different vertebrates, are usually always present. The parietal organ in at least one group of lizards extends on a slender stalk actually passing out of the skull and forming a sort of median eye on the dorsal surface of the head. In those vertebrates in which the parietal organ does not appear at all, the pineal gland seems to show tracts of structure similar to the parietal organ when it does become an eye. It will be remembered that the brow-spot seen on the frog is really the spot where the pineal gland began growing toward the exterior of the body but was cut off by the developing skull.

It is interesting to note that, notwithstanding the close relations of the pineal and parietal organs, the former receives its nerve supply from the posterior commissure while the parietal is connected with the supe-

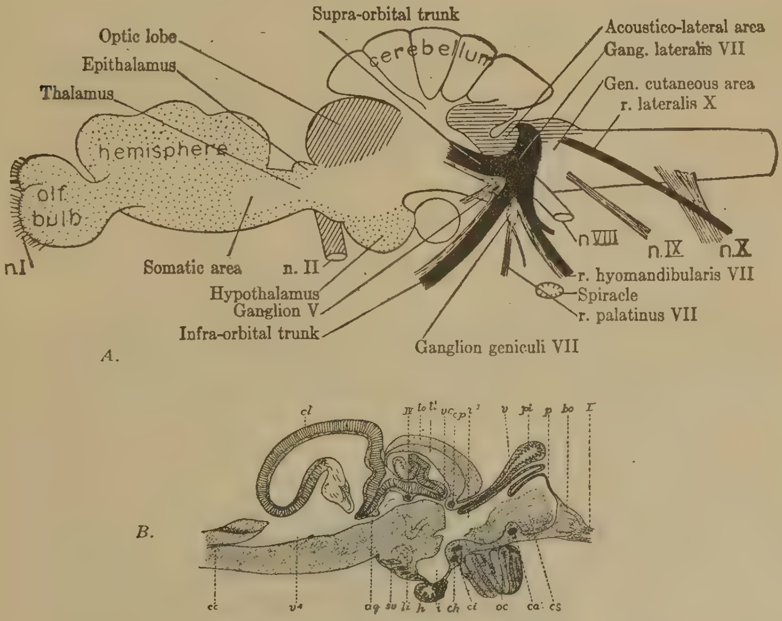


Fig. 480.

A, Side view of the brain of the dogfish *Mustelus canis*. (After Herrick.) *B*, Longitudinal section of brain of Trout. *aq*, aqueduct; *bo*, bulbus olfactorius; *ca*, *ch*, *ci*, *cp*, anterior, horizontal, inferior, and posterior commissures; *cc*, central canal; *cl*, cerebellum; *cs*, corpus striatum; *h*, hypophysis; *i*, infundibulum; *iv*, trochlearis nerve; *cc*, optic chiasma; *p*. pallium; *pi*, pinealis; *sv*, saccus vasculosus; *tl*, torus longitudinalis; *to*, tectum of optic lobes; *v*, velum transversum; v^3, v^4, ventricles; *vc*, valvula cerebelli. (From Kingsley after Rabl-Rückhard.)

rior commissure of the twixt-brain. All of these structures in the higher vertebrates are completely covered by the cerebral hemispheres growing backward over them. In many of the extinct reptiles there are large **parietal foramina** and it is supposed that these animals therefore had well developed parietal or pineal organs. Directly behind the lamina terminalis there is a chorioid plexus located in the fourth ventricle. This comes from the roof of the brain in this region and a part of it invades the third ventricle, while another part, the **inferior plexus,** sends branches through the interventricular foramina into the lateral ventricle. This provides a blood supply to the interior portions of the cerebral hemispheres.

A funnel-shaped protrusion from the floor of the diencephalon may be seen posterior and ventral to the optic chiasma known as the **infundibulum.** This connects with the **pituitary body** or **hypophysis,** which latter organ has developed from the mouth region. It is encased by the developing skull in a little bony case of its own called the **sella turcica** (Turkish saddle). The epithelium of the mouth from which the hypophysis springs, remains connected for a time to that organ and the point of ingrowth into the brain is called **Rathke's pocket** (Fig. 301, 1). It will be noticed that the pituitary body grows upward from the oral cavity just mentioned, while the infundibulum grows downward from directly behind the optic chiasma to meet it. There are really two parts to the pituitary body, both rich in blood and lymph vessels. The organ is known as a **gland of internal secretion.** Its action is supposed to be connected with the fat-storing powers of the animals; sometimes there is to be found a **postoptic commissure** connecting the ventral parts of the brain in this region.

MESENCEPHALON

The mesencephalon or mid-brain, as has already been stated, does not change very much from the way it appears in the embryo. On the dorsal surface there are two lateral swellings, the optic lobes. In the mammals these are transversely divided and are called the **corpora quadrigemina.** If they do not divide transversely they are called **corpora bigemina.** Each optic lobe is connected with fibers from the eye on the opposite side to which it itself is located. In the fishes the ventricle of the mid-brain is quite large and extends into the optic lobes, but in the higher groups of vertebrates the ventricle is reduced to a very small opening or **aqueduct.** At the anterior end of the dorsal body of the mid-brain a band of nerve fibers crosses from one side to the other. Any such cross connections are called **commissures.** These connect the two sides of the central nervous system. Cross fibers of this kind are very numerous in the spinal cord and there are also several in the brain. This particular one we have just mentioned is called the **posterior commissure.**

RHOMBENCEPHALON

THE CEREBELLUM

The cerebellum or metencephalon (Figs. 472, 481) is the coördinating organ growing behind the two cerebral hemispheres. The isthmus which connects the mid-brain and hind-brain lies directly in front of the cerebellum. The cephalic anterior wall of the cerebellum meets with the isthmus to form a transverse fold known as the **anterior medullary velum** (valve of Vieussens) which dips into the fourth ventricle. The median ridge of the cerebellum is known as the **vermis.** This is the only part of the cerebellum which the lower vertebrates possess. In some of the higher reptiles and birds, however, a small outgrowth occurs on each side called the **flocculus** and it is between the flocculus and the vermis that the cerebellar hemispheres develop in the mammals. This pushes the flocculus ventrad.

Quite a number of fibers grow from one side of the cerebellum to the other on the ventral side of the brain stem. This forms a large transverse band called the **pons** or bridge. The lower vertebrates have only a few fibers of this kind so that the pons is very narrow in them. There is a groove or tract running longitudinally from the cerebellum to the mid-brain along the side of this pons and these lateral tracts are called **anterior peduncles,** while the central or median tract is called the **middle peduncle** or **brachium pontis.** The origin in the cerebellum of the anterior peduncle is called the **nucleus dentatus.**

MEDULLA OBLONGATA

This is really a large swelling between the cephalic end of the spinal cord and the brain proper. Various marrow-centers appear in the ventral side of the floor serving as centers by which and through which efferent or outgoing fibers are redistributed to other nerve cells. The head end of the medulla, by being expanded, forces the various fiber tracts of the dorsal funiculi, as well as of the dorsal part of the lateral funiculi, over to the side of the cerebellum where they enter, bending abruptly inward and forming a cord called the **corpus restiforme,** also

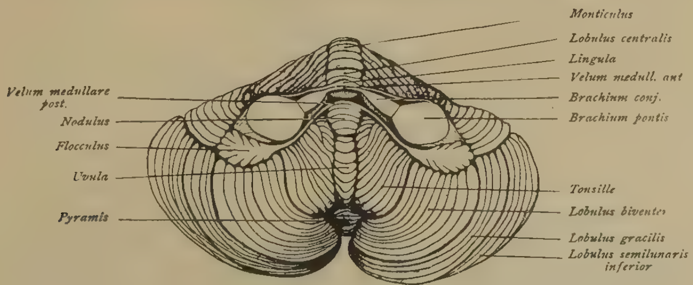


Fig. 481.

Human cerebellum viewed from below and in front. (After Villiger.)

known as the **inferior cerebellar peduncle,** on either side. The rest of the fiber tract forms a pair of bands, called **pyramids,** on the ventral surface of the medulla which extend cephalad beneath the mid-brain. These extensions are called the **cerebral peduncles** or **crura cerebri.** They are easily found in the lower vertebrates, but in the mammals the pons makes them difficult or impossible to see.

TELAE CHORIOIDEAE

While the brain is supplied by blood vessels distributed over the outer surface, extensions from the outer vessels push the roof and floors of most of the fore- and hind-brain behind them, into the ventricle of these two regions, very much on the same principle as an outgrowth of the digestive tract, such as the liver, pushes its peritoneum-covering before it. These foldings of the plates are called **telae chorioideae** or **choirioid plexuses,** and it is through these that the nourishing blood passes by osmosis into the ventricle and into the inner surfaces of the brain. It is practically impossible to remove the brain and have the fourth ventricle complete. Usually the chorioid plexus of this fourth ventricle is torn away as it is very thin in this particular region. The large open space or cavity that one sees when this has been torn away is called the **fossa rhomboidalis.**

SUMMARY OF THE BRAIN

AMPHIOXUS

The brain is extremely small, hardly as large in diameter as the rest of the neural tube. There are but two pairs of cranial nerves, which have been called olfactory and optic, but in so reduced a brain, homologies are uncertain. The sense organs consist of a median olfactory funnel opening into the neurocoele, a median eye-spot (not sensitive to light) on the anterior end of the brain, representing probably a rudiment of paired eyes. The notochord extends the entire length of the body, projecting in front of the brain. This may mean that the brain has retreated from its primitive anterior position. There is no cranium.

CYCLOSTOMATA

The brain is small but typically vertebrate in structure. The vagus nerve is not included in the cranial region. In the myxinoids, a groove runs the entire length of the dorsal surface. There are four pairs of lobes —(1) olfactory, (2) cerebral hemispheres, (3) mid-brain, and (4) cerebellum. The nasal capsule is enormously developed. The eyes are degenerate and without muscles or nerves. There is only one semi-circular canal in the inner ear. In the lampreys the cerebral hemispheres are distinct and a band-like cerebellum is recognizable. Eyes are well developed with both muscles and nerves. There are two semi-circular canals in the ear, a condition intermediate between that seen in the myxinoids and that in the true fishes, where three canals are always present.

The flexures are never very well marked and disappear entirely in the adult.

PISCES

The olfactory organs are paired and end blindly, not communicating with the pharynx as in terrestrial animals and hagfishes. The auditory organs are entirely internal, and have no communication with the exterior. They serve largely as organs of equilibration, though they also receive vibrations. The eyes are much like those of other vertebrates, except that they are lidless and have spherical lenses of short range vision in the water. The brain is small and shows no fissures. It nevertheless has all the characteristics of the vertebrate brain, though there are but ten cranial nerves (Fig. 482). The spinal cord is like that in other vertebrates.

DOGFISH

Although the brain is very small and compact, it is larger in proportion to body size than that of the cyclostomes. The most striking feature is the large size of the olfactory lobes, and the slight development of the intercerebral fissure. The cerebral hemispheres are well defined, the cerebellum is large, and overlaps anteriorly a part of the optic lobe, and posteriorly a part of the medulla oblongata. The corpora restiformia are large folds on each side of the cerebellum in front and lateral to the rhomboid fossa. The region of the thalamencephalon from which the optic nerve springs is comparatively small and slender. The spinal cord is typical and enclosed within cartilaginous neural arches. The dominant sense of the dogfish is olfactory, the sense organs consisting of large convoluted invaginations in close contact with the olfactory lobes of the brain. The eyes, although small and probably not especially keen-sighted, are well developed and connected within the brain by a rather slender optic nerve. The auditory organs are enclosed in cartilaginous

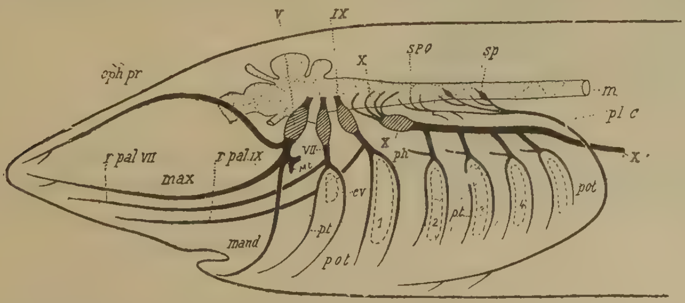


Fig. 482.

Cranial Nerves of the Fish. (Schematic.) *ev.*, spiracle; *mand.*, mandibular branch of the *V; max.*, maxillary branch of the *V; m.t.*, masticator branch of *V*; *m.*, neural cord; *oph.pr.*, deep ophthalmic branch of the *V; ph.*, pharyngeal branches of branchial nerves; *pot.*, posttrematic branch; *pt.*, pretrematic branch; *pl.c.*, cervico-branchial plexus; *r.pal. VII*, palatine branch of the *VII; r.pal. IX*, palatine branch of the *IX; sp*, spinal nerves; *sp.o.*, spinal-occipital nerves; *V* to *X*, pairs of the corresponding cranial nerves; 1 to 4, branchial slits. (From Vialleton.)

capsules and consist of three semi-circular canals, a utriculus, and a small simple sacculus. The lateral line sense organs are in grooves of the skin not completely closed. They divide into several branches in the head region, one above and one below the eye, and some in the hyomandibular region.

TELEOSTS

The vertebral column is not very compact, the vertebrae being often without a centrum. If the latter is present, it is an arch-centrum. The nasal tract has no naso-oral groove. It opens by separate nares. The brain has a much reduced cerebrum with all olfactory lobes. The pallium is usually non-nervous, causing the cerebrum to consist largely of the corpus striatum. The cerebellum is larger than a surface view shows because a great portion projects into the ventricle.

AMPHIBIA

The cerebrum is larger than the optic lobes, while the olfactory bulb is separated from the cerebrum by a long tract. The various brain parts are quite distinct. In the tailless amphibia the two halves of the cerebrum are secondarily connected by a transverse band behind the olfactory lobes so that a gap is left farther back.

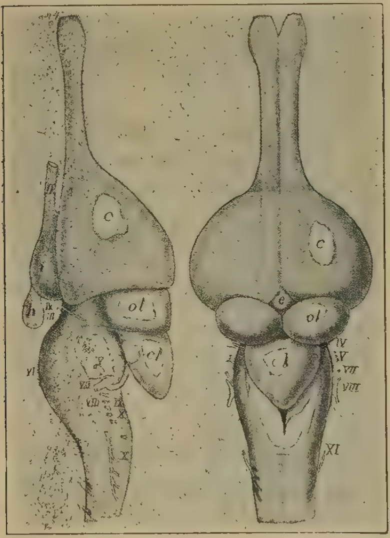


Fig. 483.
Side and dorsal views of young Alligator. *c*, cerebrum; *cl*, cerebellum; *e*, epiphysial structures; *h*, hypophysis; *i*, infundibulum; *ol*, optic lobes; *II-XII*, cranial nerves. (From Kingsley after Herrick.)

The telencephalon is larger than in fishes on account of the pallium being invaded with nervous matter on the inner side. There is no true cortex.

The optic lobes are large and the pineal gland reaches the cranial roof in the tailless amphibia. In the gymnophiones there is a pontal flexure which brings the pituitary gland beneath the medulla oblongata.

REPTILIA

There is an advance in the nervous system beyond the amphibia. The cerebral hemispheres are larger and the cerebellum more complete and a cortex is developed. Something of both pontal and nuchal flexures is retained. There may be a beginning of a temporal lobe. A parietal eye is well developed in lacertilia. It is rudimentary in other groups. The olfactory lobes are merged in the hemispheres. The eyes are small, the pupil round, and the iris unusually dark in color. The thalami develop so far as to reduce the third ventricle to a narrow slit, even causing the two edges to unite. This forms the soft commissure or **intermediate mass** of the mammalian brain. The sense of hearing is not very acute.

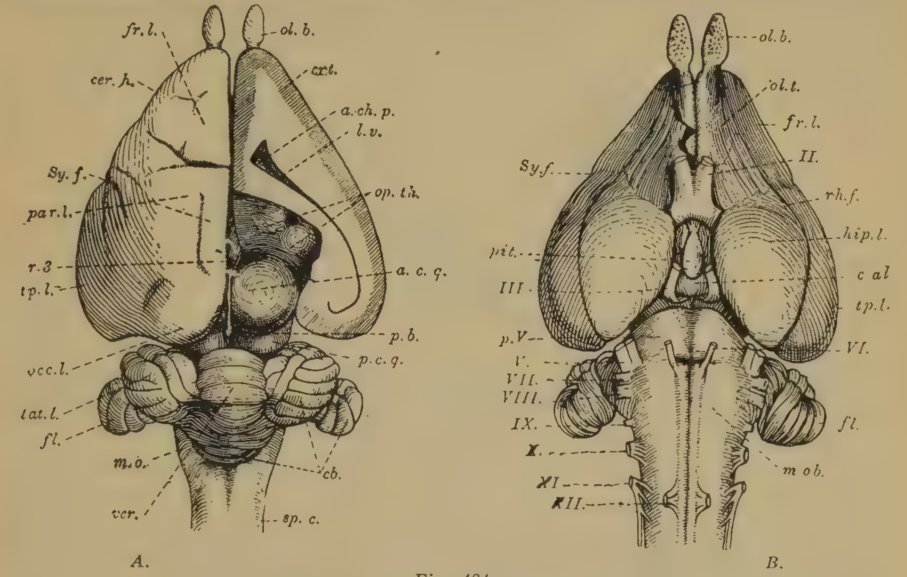


Fig. 484.

A. The brain of a rabbit, seen from above with part of the right cerebral hemisphere cut away. *a.c.q.*, Anterior corpus quadrigeminum; *a.ch.p.*, anterior choroid plexus; *cb.*, cerebellum; *cer.h.*, cerebral hemisphere; *crt.*, cortex; *fl.*, flocculus; *fr.l.*, frontal lobe of cerebral hemisphere; *l.v.*, lateral ventricle; *lat.l.*, lateral lobe of cerebellum; *m.o.*, medulla oblongata; *occ.l.*, occipital lobe of cerebral hemisphere; *ol b.*, olfactory bulb; *op.th.*, optic thalamus; *p.b.*, pineal body; *p.c.q.*, posterior corpus quadrigeminum; *par.l.*, parietal lobe of cerebral hemisphere; *r.3*, roof of third ventricle; *sp.c.*, spinal cord; *Sy.f.*, Sylvian fissure; *tp.l.*, temporal lobe of cerebral hemisphere; *ver.*, vermis.

B. The brain of a rabbit from below. *c.al.*, corpus albicans; *fl.*, flocculus; *fr.l.*, frontal lobe of the cerebral hemisphere; *hip.l.*, hippocampal lobe; *m.ob.*, medulla oblongata; *ol.b.*, olfactory bulb; *ol.t.*, olfactory tract; *p.V.*, pons Varolii; *pit.*, pituitary body; *rh f.*, rhinal fissure; *Sy.f.*, Sylvian fissure; *tp.l.*, temporal lobe of the cerebral hemisphere; *II.-XII.*, roots of the cranial nerves. (From Borradaile.)

The tympanic membrane is thin and exposed, and is connected with the auditory organ by a slender columellar bone. The sense of smell is the keenest of the senses in the turtle, both in the air and in the water. In correlation with the keen olfactory sense, the olfactory lobes of the brain are highly developed. In the crocodile (Fig. 483), the brain is decidedly advanced in structure for a reptilian brain. The large cerebral hemispheres are especially noteworthy. The tympanic membrane is sunk in a pit. This is a tendency that is carried much further in the birds and mammals.

AVES

The brain is very short and broad; the cerebrum is large but not convoluted. The cerebellum is very large and complex. All three flexures are partially retained throughout life. The optic lobes are well developed. The olfactory lobes are rudimentary, indicating a poor sense of smell. The olfactory epithelium is poorly developed, and sense of taste is almost as poorly developed as the olfactory sense. The inner ear, especially the cochlea, is more complex than in reptiles. The eye of birds is large and highly organized, probably keener than that of any other animal. Sclerotic plates cover the eyeball. A fan-shaped pecten (Fig. 490) of unknown function is inserted in the vitreous humor.

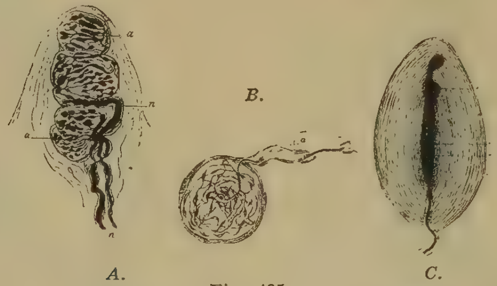


Fig. 485.

Nerve end-organs. *A*, longitudinal section of tactile papilla, containing a Meissner's corpuscle. *B*, Section through a terminal corpuscle (end-bulb of Krause) from the conjunctiva. *C*, Section of a Pacinian corpuscle. The nerve fiber, *n,m*, enters the capsule through the channel *f*, and has its terminal branches at *a*. (*A*, *C*, from Ranvier, *B*, from Dogiel.)

MAMMALIA

It seems that some of the archaic mammals did not have a more highly developed brain than reptiles. Modern mammals, however, especially the higher groups, have a brain that is much more highly developed than that of all other forms.

In these higher groups the brain is relatively large (Figs. 472, 484), the cerebral hemispheres showing the greatest increase. The increase is practically confined to the pallium (neopallium).

There is an elaborate system of commissures to connect the two sides of the brain, the corpus callosum being the most important. In fact, the corpus callosum is largest in the highest groups.

In the lower animals the olfactory lobes lie at the tip of the cerebrum, but in the higher forms the pallial increase pushes the frontal lobes forward so that the olfactory lobes are brought to the lower surface and are separated from the cerebrum proper by a rhinal fissure on each side.

The olfactory tract and the hippocampal tract connect the olfactory lobes with regions farther back, but in man the hippocampal tract is largely rudimentary, the corpus callosum acting as the great connecting region.

The great numbers of fibers from the increased pallium form the **corona radiata** which connects the cortex with the more posterior portions of the brain. And, as connection is made through the thalami, the thalamic regions become greatly enlarged, extend into the third ventricle and reduce that to a mere slit. Where the two walls come in contact the intermediate mass is developed.

The mesencephalic lobes are four in number, now called the corpora quadrigemina, only the anterior pair being connected with the optic nerves, the posterior pair being connected with the sense of hearing.

An important point in the understanding of certain brain structures is the knowledge that the pallium causes a folding so that the original postero-ventral end of the cerebrum, lateral to the pyriform lobe, is pushed below and to the outside of the lateral parts of the hemispheres, the fissure of Sylvius marking the place of folding. It is at the bottom of this fissure that the **island of Reil** is found, which is only the covered part of the sides of the hemispheres.

All higher forms of mammals have the hemispheres arranged in many convolutions. This permits an increase in surface without necessitating a great bulk increase. However, some animals with less mental ability apparently have more convolutions than the more highly organized, so that it cannot definitely be said that greater convolutions necessarily carry greater mental power.*

The mammalian cerebellum, while better developed than that of reptiles, is not as highly developed as that of birds.

Ornithorhynchus (Fig. 472) has the most primitive brain of all mammals. It is small, the cerebral hemispheres are smooth and lack all convolutions. This animal is aquatic in its habits, living in stagnant water and feeding chiefly on mollusks, crustaceans, and worms which it secured by scooping up the muddy bottom with its bird-like bill.

THE ORGANS OF SPECIAL SENSE

It will be remembered that one of the outstanding characteristics of living matter is its irritability. **Contractility** is usually added to irritability when living protoplasm is discussed. It has already been shown that various functions in the body may be carried on when the entire nerve supply to that portion has been destroyed. We may therefore say, that while irritability and contractility are essential parts of living matter, the irritability which causes contractility need not be brought about by a definite system of nerves, although the nerves do carry the stimulus from one part of the body to another, thus coördinating the various parts and permitting them to work together for some common end.

In all higher forms, there are external organs of special sense, such as the nose, the eye, and the ear. In some of the lower forms such as the earthworm, we found, that while there are no definite eyes, the earthworm nevertheless responded to light thrown upon its body by moving out of the way as rapidly as it could. We know from this experiment that the earthworm is sensitive to light, and that therefore there are definite sensory regions, more or less specialized, in its skin by which it can receive a stimulus from light.

It would profit an animal little to be able to receive a stimulus if it could not in some way move itself toward or away from such stimulus. The muscles by which an animal may move out of harm's way or toward a food stimulus, and the glands which can secrete substances that will repel an enemy serve such a purpose.

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* *Echidna* has more brain convolutions per body-weight than man.

In order, then, that an animal may profit by the various stimuli it encounters, it must have (1), a **sensory region** or surface of some kind which such stimuli may effect; (2), it must have **an organ,** such as muscles or glands, which will permit a reaction to the stimuli, (3, it must have a **conducting mechanism** by which the stimulus may be sent to the reacting organs.

The nerve cells become specialized in structure (or in their manner of connection) in three different ways, namely: (1) they may develop sensitivity and form organs of special sense. These nerve cells then receive specific stimuli. (2) If the nerve cell develops conductivity, **it can** transmit impulses, such as **sensory,** to the central nervous system, or **motor from** the central nervous system. The conducting parts formed by this second group of specialized neurons form **nerve tracts.** (3) The third type of specialization of nerve cells is found in the central nervous system itself. This type forms what are called correlation and association fibers in the sensory field, and coördination fibers in the motor field.

In practically all parts of the skin, there are tiny nerve endings, commonly called **free nerve terminations,** by which we recognize substances when we come in contact with them. Then there are certain parts of the tips of the fingers where definite **end organs** are found, and where the sense of touch is quite highly developed. The nerve endings in such special tactile regions are much more complicated than in the simple free nerve terminations. Figure 484 shows some of the various types of these tactile corpuscles.

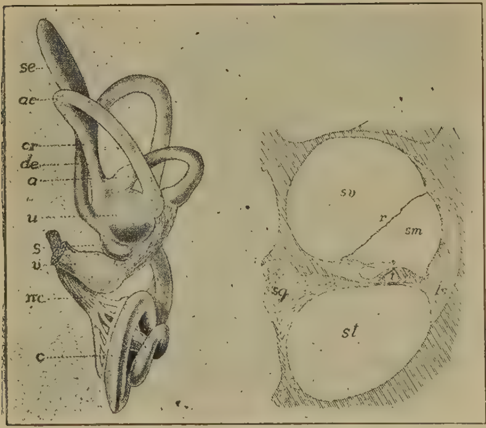


Fig. 486.

A, Labyrinth of human embryo, 30 mm. long. *B*, Section through the cochlea of a guinea pig. *a.*, ampullus; *ac.*, anterior canal; *c.*, cochlea; *cr.*, crus; *dc.*, endolymph duct; *ls.*, spiral ligament; *nc.*, cochlear nerve; *r.*, Reissner's or vestibular membrane; *s.*, sacculus; *se.*, endolymph sac; *sg*, spiral ganglion; *sm,st,sv.*, scalae media (ductus cochlearis), tympani and vestibuli; *t*. tunnel; *u.*, utriculus; *v.*, vestibular nerve. (From Kingsley, *A* after Streeter and *B* after Schneider.)

In our embryological study we have already discussed the lateral line organs (Figs. 340, 479), which are in all probability tactile, and probably even sound-perceiving organs. In the higher vertebrates there are three great divisions of the ear, namely, an external, internal, and middle ear. Of these three portions, the inner ear is the most primitive. All lower vertebrates that develop a definite ear organ at all begin by having simply an **inner ear** (Fig. 19). To this the next succeeding higher forms add the **middle ear** or **tympanum**, while the highest forms add the outer ear.

The Inner Ear. This consists of a mere area of thickened ectoderm on each side of the head, between the seventh and ninth cranial nerves. A review of the embryology of the ear will recall the cup-shaped auditory vesicle. In the dogfish, the cavity of this remains connected with the exterior by a slender tube known as the **endolymph duct** (Fig. 486). In the frog and in higher forms, there is no open auditory cup. There are two layers of ectoderm, the outer one forming an unbroken sheet across the cup. In the dogfish, these endolymph ducts can be seen as external portions on the top of the head.

The distal end of this endolymph duct becomes enlarged, the enlargement being called the **sacculus endolymphaticus.** In the frog and other amphibia, the ducts of both sides often unite dorsal to the brain, while the other parts branch and extend into the spinal canal in a root-like manner. In the frog definite diverticula are sent into the so-called calcareous glands, surrounding the basal portion of the spinal nerves.

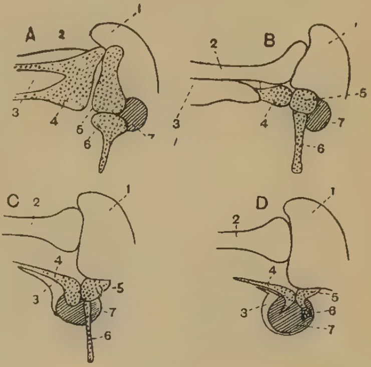


Fig. 487.

Four diagrams to illustrate the variation of ear-bones in Mammalia. The diagrams represent the bones of the back of the lower jaw viewed from the inner side. The tympanic membrane is cross hatched and cartilage bones are covered with small circles, whilst membrance bones are left unshaded.

A. Condition in early Theromorphous Reptile. The articular and quadrate are large, and the dentary does not meet the squamosal. *B.* Condition in later Theromorphous Reptile. The dentary has met the squamosal, and the quadrate and articular are reduced in size. *C.* Condition in hypothetical form, the link between Theromorpha and Mammalia. The supra-angular has begun to extend along the border of the tympanic membrane. *D.* Condition in primitive Mammalia (Prototheria). 1. Squamosal. 2. Dentary. 3. Supra-angular. 4. Articular (=Malleus). 5. Quadrate (=Incus). 6. Columella auris (=Stapes). 7. Tympanic membrane. (From Shipley and MacBride.)

The auditory vesicle constricts into two chambers, an upper vestibule or **utriculus** and a lower **sacculus,** connected by a narrow **sacculo-utricular canal.** Three outgrowths now take place, one each from the outer, posterior, and lateral walls of the utriculus; the one from the lateral wall lies in a horizontal plane, the others in vertical planes. These outgrowths form tubes, and as they are circular in outline, they are called the **semi-circular canals.** Some of the sensory epithelium has spread into all of these regions, but a definite patch of this sensory epithelium can be seen in each of the semi-circular canals, and it is around this patch that the wall of the canal expands to form an **ampulla.** Figure 486 will have to be studied and the model of the ear seen or an ear definitely worked out in one of the animals to make this clear.

In forms higher than fish and amphibia, there is a little pocket called the **lagena,** given off from the posterior side of the sacculus. Sensory epithelium extends into this pocket, and in the higher forms the lagena becomes a peculiar structure called the **cochlear duct.**

The structures of the internal ear just mentioned form the **membranous labyrinth,** which is filled with a fluid called endolymph, in which a number of solid particles, called **otoliths,** are found. The otoliths are very tiny crystals of calcium carbonate which cause the endolymph to have a milky appearance. In the true fishes these tiny crystals have become aggregated into one or more **ear stones** of considerable size. In the dogfish, as the endolymph duct has an opening to the outside, sand from the exterior may also form part of the otoliths.

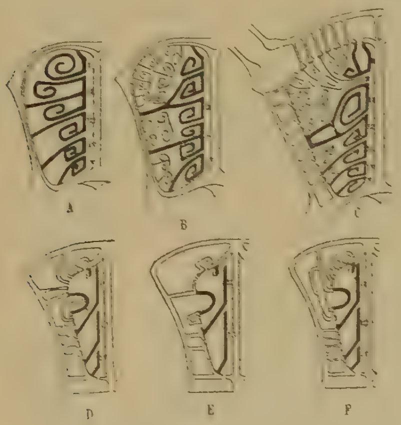


Fig. 488.

Diagrams of ethmoturbinals in Mammals. *A*, Type showing endoturbinalia alone. *B*, Type with endoturbinalia (heavy lines) and two ranks of ectoturbinalia. *C*, Turbinals with pneumatic cavities in the ox. *D,E,F*, three actual cases in man, showing individual variation. (From Wilder after Paulli.)

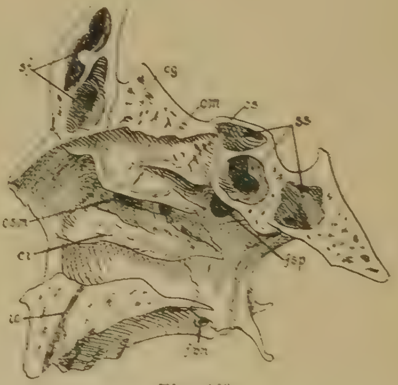


Fig. 489.

Lateral wall of nasal cavity of man. *cg.*, crista galli; *ci.cm.cs.*, inferior, middle and superior conchae; *fpm.*, foramen palatinum majus; *fsp.*, sphenopalatine foramen; *ic.*, incisive canal; *osm.*, opening of maxillary sinus; *sf*, frontal sinus; *ss.*, sphenoidal sinus. (After Corning.)

Cartilage then appears, practically covering the membranous labyrinth. This becomes the **skeletal** (in higher forms the bony) **labyrinth,** and is separated from the membranous labyrinth by a small space filled with a fluid called **perilymph.** As ossification then takes place in the cartilage, the ear bones are formed (Fig. 487). There are two openings into the middle ear, the **fenestra tympani,** also called the **fenestra rotunda,** which is closed by a membrane, and the upper opening, known as the **fenestra ovale** or the **vestibule.** The **stapes** (Fig. 487), a small piece of cartilage or bone, is held in place by the membrane.

The lagena grows quite rapidly and coils up into a spiral, in fact, it extends to the skeletal labyrinth, thus dividing the perilymph space into two spiral tubes called **scalae** (Fig. 486). The upper one is called the **scala vestibuli,** and the lower the **scala tympani,** while the lagena itself forms the **scala media,** also called the cochlear duct. The bony labyrinth which contains the scala is named the **cochlea.**

As the cochlea only develops in the higher forms, and as our own sense of hearing is very incomplete without this structure, we must come to the conclusion that the lower forms of life which do not possess such an organ must either hear entirely different sounds from those that we hear, or some other part of the structures they do have must do work other than that done in man. A very complicated **organ of Corti** arises within the scala media. Fine hair-like structures develop in the organ of Corti which can only be worked out microscopically and with great difficulty. There is a membrane extending out from the middle wall over some of the hair cells in the organ of Corti, called the **membrana tectoria.** Various functions have been assigned to this membrane, one of them being the ability to recognize pitch in sound. Birds, however, have no organ of Corti at all, and the evidence is quite conclusive that they can distinguish pitch.

The Middle Ear or Tympanic Cavity. This first appears in the **Anura,** that is, in the tailless amphibians such as the frog. We have already seen from our dissection of the frog that a tympanic cavity connects with the pharynx by a slender duct, the **Eustachian** or **auditory tube.** Externally there was a tympanic membrane extending across the fenestra ovale, through which sounds were transmitted to the inner ear. The Eustachian tube is usually considered the homologue of the narrow internal end of the spiracle in the dogfish. Frogs, birds, and reptiles have a chain of ear bones consisting of a columella and stapes, while in the mammals the **incus** and **malleus replace the columella** (Fig. 487).

The External Ear. It will be remembered that in the frog the tympanic membrane lies on a level with the surface of the head. In higher forms the tympanic membrane lies at the bottom of a canal called the **external auditory meatus.** In most mammals, with the exception of those that live in water such as the whales and seals, there is even an **external conch** developed behind the meatus, so as to assist in collecting the sound waves and directing them internally. In some of the birds, feathers are arranged about the external meatus to function as does this conch.

It is to be remembered that the ear not only serves the purpose of taking in and interpreting sounds, but that the semi-circular canals, lying as they do in three dimensions of space and filled with the endolymph, function somewhat similar to a carpenter's level, sending sensations to the brain by which the animal recognizes the position of its own body relative to its surrounding environment. We may therefore think of the semi-circular canals as an **organ of equilibration.**

THE NOSE

The real sensory part of the smelling apparatus is always restricted to one or two small patches of olfactory epithelium near the end of the head. As the olfactory sac sinks beneath the surface of the ectoderm, it remains connected by a pair of external openings called the **nares.**

As the dorsal portion of the head then continues growing, the nares are carried toward the tip of the snout or, in the elasmobranchs, toward the ventral side of the head. We have already discussed the forms of the nasal capsules with the skeletal system. In the higher groups, glands form which keep the epithelium moist.

Beginning with the amphibia and appearing in the higher groups of animals, there is **an accessory olfactory organ** known as the **organ of Jacobson** (Fig. 339), which is probably used to test the character of food while it is in the mouth. The first and fifth cranial nerves supply the organ of Jacobson, which lies near the internal nostrils.

Cyclostomes have but a single nostril. In all other vertebrates there are paired nostrils called nares. In the cyclostomes, the nostril is directly connected with the hypophysis, a condition not found in any other vertebrates. In animals living within the water there are folds formed on one side of each naris which practically divides it into two, in fact, in many of the teleosts, each primitive nostril is actually divided into two; this permits water to circulate through the olfactory sac, thus carrying various sensations of odors to the extensive sensory surface of the sac.

In air-breathing vertebrates, including lung fishes, contrary to the water-breathing groups, the nasal cavity has a connection with the alimentary tract. In some elasmobranchs the first traces are seen of an arrangement for drawing air over the sensory surface. This arrangement is an oro-nasal groove which leads from each nostril to the angle of the mouth (Fig. 296, nas. gr); in fact, this groove may, in some species, form a definite tube. From the lung fishes upward a similar groove is formed on each side before the skeletal parts form. As this closes, the edges of each groove unite to form a duct leading from the nostril into the oral cavity where an internal naris or choana is thus formed. The position of these choanae varies in the different groups of animals. Maxillary and pre-maxillary bones arise ventral to the nasal passage, causing the ducts to appear as though running through the skull.

If the oro-nasal groove does not close, harelip results, just as the failure of the palatines to come together causes a cleft palate.

In some of the urodeles a projection occurs from the lateral wall. This is one of the first indications in the rising groups of vertebrates of the conchae, well known in all higher groups. Often the ventral portion of the nasal passage is lined only with ordinary epithelium. This portion is then called the **respiratory duct.** The more dorsal portion lining the tract with sensory epithelium is known as the **olfactory duct.** The organ of Jacobson (Fig. 339) is on the medial side of the nasal cavity in the lower urodeles. In the higher urodeles it is ventral, while in the highest it has rotated to the lateral side.

The external nares are closed by the smooth muscles in some of the amphibia. There is little change in the choanae between amphibia and reptiles. The reptiles, however, show a tendency to have a differentiated anterior region known as the **atrium** or **vestibule,** a middle region connected with the original region, and a posterior region called the **naso-pharyngeal duct.** The naso-pharyngeal duct may vary in length according to whether the choanae are anterior or posterior in position. The crocodiles show an extreme elongation due to the palatines and pterygoids growing inwardly, which causes the internal nares to be pushed to the hinder end of the skull. There is a single concha, which is supported by bone in the lateral wall of the nose of reptiles. This is rather weak, however, in turtles and in the crocodiles. It is divided in front, while a "pseudobranch" develops above and behind the true concha. It is only in the snakes and lizards that Jacobson's organ occurs (Fig. 339), and that only as a simple pocket ventral and medial to the nasal cavity near the nasal septum.

In birds there is an anterior and inferior concha vestibuli, and also a middle and a superior fold, formed by three folds on the wall of each nasal cavity. There is no olfactory epithelium formed on the vestibular conch; it is present on the middle conch immediately before hatching, and disappears immediately after hatching, so that the upper conch is the sole seat of smell in the adult. Jacobson's organ is only found in embryos.

In mammals much greater complication sets in. The naso-pharyngeal duct becomes elongated, while the olfactory area lies directly below a portion of the brain cavity. The interior arrangement of the bones formed within the nose forms what is called the **nasal labyrinth.** The ethmo-turbinals, the naso-turbinals, and the maxillo-turbinals are the supporting bones or cartilage of the folds of the labyrinth. This arrangement permits a great expansion of sensory surface, while the supporting structures keep the folds from touching each other.

In those animals whose sense of smell is very low, not only the folds, but the bones themselves, may be likewise reduced.

The maxillo-turbinals and the naso-turbinals arise from the lateral wall of the nasal cavity. The ethmo-turbinals are outgrowths from the ethmoid bone, growing out from the upper hinder part of the septum and extending to the lateral wall. This causes the ethmo-turbinals to insinuate themselves between the hinder ends of the other two. Any of these turbinals may divide in turn. The subdivision of the ethmo-turbinals may be of varying heights so that to form the ecto and ento-turbinals the naso-turbinals may disappear in the adult. The epithelium of the maxillo-turbinals is not sensory, so that it is assumed that this portion of epithelium serves only to warm and moisten the air in its passage to the lungs. The various forms which the ethmo-turbinals assume in mammals may be seen from Figure 488. Peter gives the following table of homologies of the nasal labyrinth in the amniotes:

I. Concha of the anterior epithelium: concha vestibuli (birds).

II. Conchae of the primitive sensory epithelium:
    1. Arising from the lateral wall (conchae laterales).
        A. Anterior:
            (a) Primary, ventral: concha of reptiles; middle concha of birds; maxillo-turbinals of mammals.
            (b) Secondary, dorsal: Upper or posterior of birds; naso-turbinals of mammals (Pseudoconch of crocodiles).
        B. Arising from the posterior part: conchae obtectae of mammals.
    2. Arising from the primitively median wall: ethmo-turbinals of mammals, numbered from in front backward.

Jacobson's organ (Fig. 339), also called the **vomero-nasal organ,** can be seen in the embryo of most mammals as a pocket on the lower middle side of each nasal cavity. It opens near the duct from Stenson's gland in rodents and in man, while in other mammals its duct is apparently cut off from the nasal cavity and opens into the naso-palatal canal. Its middle wall is covered with a sensory epithelium to which branches of the olfactory nerve extend. The organ degenerates in adult primates.

There are two kinds of glands in the nasal cavity, known as **Bowman's glands,** which are the smaller, and **Stenson's gland,** which lies in the lateral ventral wall and opens into the vestibule. There are usually sinuses in the bones of the skull connected with the nasal cavity by various openings. Figure 489 shows several of the principal sinuses in the bones, such as the maxillary, frontal, and sphenoidal.

All mammals have an external fleshy nose supported by nasal bones and cartilage, but in swine the fleshy portion forms a proboscis of considerable size, and in the elephant this fleshy proboscis extends tremendously to form the trunk.

It is interesting that while most mammals have a well developed sense of smell, in seals, whale-bone whales, and primates, it is not very great, while it is practically absent in the toothed-whales. Often the olfactory nerve disappears entirely.

THE EYE (Figs. 18, 289, 338)

A review of the embryology of the eye in both frog and chick will make clear how the eye cup, vesicle, stalk, and lens are formed.

A detailed description of the eye must be sought in text-books of histology. Here we can give but a general outline so as to make intelligible the dissection and comparison of the eye in the various groups of animals studied. The adult eyeball is made up of three tunics, tabulated as follows:

I. Tunica Externa.
    1. Sclera.
    2. Cornea.

II. Tunica Media.
  1. Choroid coat.
  2. Iris.
  3. Ciliary Body.

III. Tunica Interna.
  1. Retina.
  2. Pigment membrane.

The refracting media, or transparent media of the eye traversed by a ray of light are:

1. The cornea.
2. Aqueous humor.
3. Lens.
4. Vitreous humor.

Each of these layers is made up of other layers in turn and can be best understood from a careful observation of Figure 18. The retina is made up of several layers of ganglion and sensory cells. The sensory cells lie toward the outside of the eyeball and have a rod or cone toward their outer end. This is the real seeing-portion of the cell. The cells themselves are called rod and cone cells (Fig. 490, C).

The yellow spot at the center of the retina where vision is the most distinct is called the **macula lutea** or **fovea centralis**.

From what has been said in our general discussion of the central nervous system, we have seen that the surface lining of the central canal of brain and spinal cord is the sensory portion. This is called the **ependyma**. Originally the rods and cones are on the primitive outer surface, and the ganglion cells and nerve fibers are on the ventral surface, of the ectoderm. The rods and cones, therefore, correspond to other sensory organs, such as the organs of the lateral line, taste buds, etc. Now for the light to get to the rods and cones, it is necessary that such light traverse the whole retina and then the nervous impulses have to travel back through the same layer to reach the optic nerve.

It is well at this point to compare the vertebrate eye which we are now studying with the parietal eye of the reptiles.

The space between lens and retina is filled with a semi-solid substance called the vitreous humor. What this vitreous substance is and how it arises is still in dispute.

The outer wall of the optic cup forms the pigmented epithelium of the eye; the black pigment developed in this region ultimately surrounds and isolates the rods and cones, so that only light which falls directly upon them can affect them. It is from the outer portion of this pigmented layer that the various tunics of the eye develop. These tunics of the eye are mesenchymal in origin. The tunica vasculosa which surrounds the retina is divided into a **choroid** and a **ciliary portion**. The

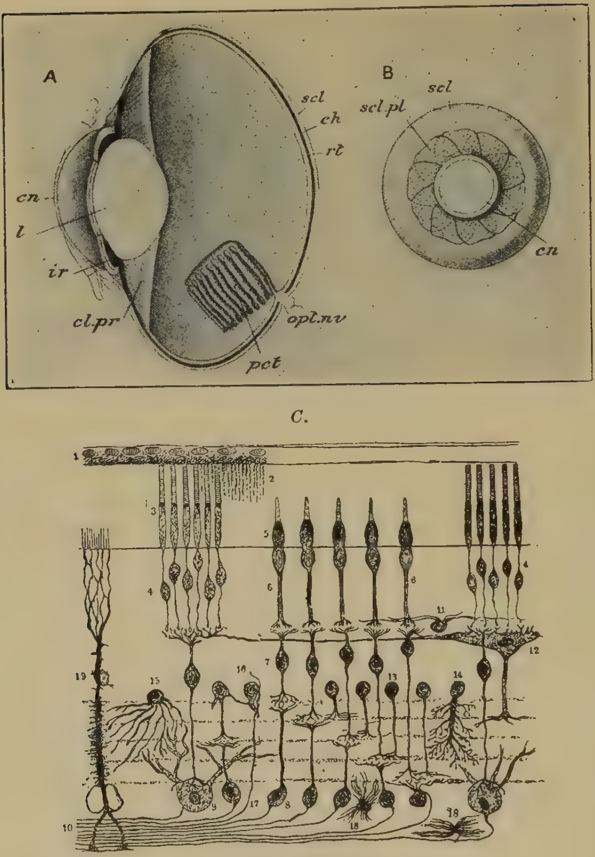


Fig. 490.

A and *B*, The eye of Columba livia.

A, in sagittal section; *B*, entire organ, external aspect. *cn.*, cornea; *ch.*, choroid; *cl.pr.*, ciliary processes; *ir.*, iris; *l.*, lens; *opt.nv.*, optic nerve; *pct.*, pecten; *rt.*, retina; *scl.ps.*, sclerotic plates. (From Parker and Haswell after Vogt and Yung.)

C. Schematic representation of the sensory apparatus in the retina of the human eye.

1. layer of pigment cells next to the choroid; 2, processes of the pigment cells; 3, rods; 4, bodies of rod-cells; 5, cones; 6, axones of cone cells; 7, cone-bipolar cells; 8, 9, ganglion cells; 10, optic nerve fibers (axones of ganglion cells); 11, 12, horizontal cells; 13, 14, 15, 16, cells of different type; functions unknown; 17, fibres (probably axones) of cells having bodies in the brain; 18, neuroglia cells; 19, radial fiber (Müller's fiber: part of the sustentacular syncytial framework of modified neuroglia). (From Dunlap after Merkle-Henle).

choroid contains a great many blood vessels and covers the greater portion of the eyeball. It meets the front of the eyeball with the circular ciliary process, in which there are various ciliary muscles by which the lens is moved toward or away from the retina so as to alter its shape. This changes its focal point. The change of focal point is known as **accommodation of the eye.** The center of the ciliary process is the **iris,** a sort of circular curtain, with a central opening. The opening is known as the **pupil.** There are circular muscles called **sphincter pupillae** and **dilator pupillae,** which contract and enlarge the pupil respectively.

The outer capsule surrounding the various layers just discussed, consists of a **sclera,** which covers the proximal side of the eye, and the **cornea** which is transparent, and through which light first passes before reaching the lens. The sclera is usually white, and is covered externally in part by the **conjunctiva,** which is modified epithelium. In some of the extinct amphibia, and in many of the modern reptiles and birds, portions of the sclera ossify and form a ring of **sclerotic bones.** Snakes and crocodiles, however, do not develop sclerotic bones. In the sturgeon, and in many teleosts, there are two or more **dermal bones developed on the sclera,** and in some of the sharks and teleosts there are calcifications to be found also, but these are not true sclerotic bones. Between the lens and the cornea there is an opening, partly divided by the iris into **anterior** and **posterior chambers.** The two chambers are in direct connection through the pupil and are filled with a liquid, called the **aqueous humor.**

All that has been discussed so far in connection with the eye forms the eyeball proper, also called the **bulbus oculi.** The eyeball is moved in its socket by six muscles, best understood by studying Figure 466.

Amphibia possess a distinct muscle which draws the eyeball back into its socket. This is known as the **retractor bulbi.** Even some of the jaw muscles may assist in elevating and depressing the ball. In the dogfish there is a cartilaginous rod, called the **optic pedicle** extending from the eyeball to the skull, this being replaced in the bony fishes by a fibrous band, the **tenaculum.**

The eyelid varies in different groups. The upper and lower, as in the higher vertebrates, and the third lid, called the **nictitating membrane,** usually drawn horizontally across the front from the inner angle of the eye, all form beneath the lower lid. The eyelids themselves have a lining which lies next to the eye and which is a continuation of the conjunctiva already mentioned. In the higher mammals the nictitating membrane appears as a rudimentary fold called the **plica semilunaris** in the inner angle of the eye (Fig. 4).

There are no glands connected with the eye in cyclostomes or fishes. In amphibia they are of the rudimentary type, but in both reptiles and birds they are divided into two groups, **Harder's glands** (nictitating glands), lying near the inner angle and the **true lachrymal** or **tear glands,** lying in the outer angle.

The tear glands in mammals ultimately come to lie beneath the upper lid and lead, by many ducts, into the conjunctival sac, while Harder's glands degenerate. The tears secreted by the lachrymal glands pass over the conjunctiva and are collected at the inner angle of the eye, where they then pass through the lachrymal duct into the cavity of the nose.

The eyes of the cyclostomes are of a very degenerate type. In the next higher group, namely, the myxinoids, the lens and the eye muscles are lacking, while the iris, cornea, and sclera seem quite as one layer.

Fishes have a flattened cornea and a spherical lens, and long rods in the retina. There is also a peculiar **falciform process** of vascular and muscular structure that enters the retinal cup through the **choroid fissure,** where it expands (Fig. 282, B). This expansion is called the **campanula Halleri.** As there are no ciliary muscles it may be that this process serves as a means of accommodation. In the flat fishes one of the eyes migrates during the embryological development so that both eyes are found on one side of the head (Fig. 371).

In birds and reptiles there is usually a process developed from the inner surface of the retina forming the **pecten** of birds, already described, while in reptiles it is merely a small cone-shaped process at the point of entrance of the optic nerve. In birds it is quite fan-shaped. Its function is not known, although it is rich in sensory cells.

In mammals the pupil varies from a vertical slit in cats to a horizontal opening in whales and many ungulates.

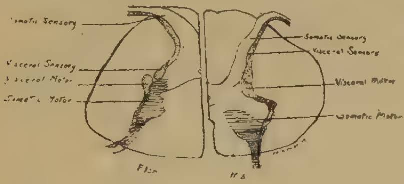
The lids may fuse together during embryological development and separate again some time after birth. At the edges of the lids, there are eyelashes or cilia, and immediately interior to these are the ducts of sebaceous glands called Meibomian or tarsal glands, the glands themselves lying in the substance of the lids.

There is a **retractor muscle** of the eyeball in the ungulates. In most mammals the **superior oblique muscle** of the eye passes through a loop known as a **trochlea** before becoming attached to the eyeball proper.

Eyes may be of various sizes even in mammals. The blind marsupial **Notoryctes** of Australia have neither lens nor differentiation in the cornea, sclera, or choroid, while the retina is lacking in rod and cone cells. In the mole the eye is quite similar to that of other mammals, but the lids remain fused in the adult.

THE PERIPHERAL NERVOUS SYSTEM

All nerves running to and from the central nervous system constitute the peripheral nervous system. We have already seen in our embryological study how the spinal nerves have their origin in the neural crests, which have been left on each side as the neural tube closed. Figures 470 and 492 show how the dorsal and ventral roots come together before sending out dorsal, ventral, and visceral rami. Not only is the dorsal root of the spinal nerve **sensory** and the ventral root **motor** in action, but each root has two types of nerve fibres within it. These are the **somatic sensory** and the **somatic motor fibers,** which are distributed to the skin as well as to the external sense organs and voluntary muscles. Then there are the **visceral sensory** and **visceral motor fibers** which supply the viscera and circulatory system (Fig. 491). The dorsal and ventral rami, after leaving the connection formed by dorsal and ventral roots, contain mostly somatic fibers with just a few of the visceral type. The visceral ramus contains visceral fibers alone.



Fish. Man.

Fig. 491.

Diagram of cross section of spinal cord to show relation of the function columns of gray matter to the nerve roots. Left half of figure is that of a fish and right half that of the spinal cord of man. Note the relatively greater size of the dorsal gray columns and dorsal funiculi in man. This is correlated with the greater importance in man of the assembling connections between the cord and the frame.

In the lower vertebrates, some of the visceral motor fibers actually pass through the dorsal root, so that one cannot in all strictness say that the dorsal root is exclusively sensory, but in mammals, dorsal roots are purely sensory, and ventral roots purely motor.

The visceral fibers of the spinal nerves are practically all **efferent** or **motor** in function. They do not pass to their terminal organs, such as the smooth muscles, glands, etc., directly, but always end in some sympathetic ganglion where there is a functional connection made. From this ganglion the impulse is then carried to a peripheral organ by axones from the sympathetic nerve cells.

In the lower vertebrates, in the regions where the limbs form, there are usually networks or **plexuses** formed. These are paired, as "cervico-brachial" for the fore-limbs, and "lumbo-sacral" for the hind-limbs, while in the higher vertebrates these have separated and there are definate cervical. brachial, lumbar and sacral plexuses. There are usually a great number of nerves (up to about tweny-five) going to form a plexus, in fact, twenty-five is the largest number known, and this occurs in the pectoral fin of skates (Fig. 336).

As there is also a plexus in snakes and limbless lizards in the regions where limbs usually develop, it is often thought that these animals descended from limbed ancestors, although no trace of limbs occur during their embryological development. It is from these plexuses that dorsal and ventral branches of nerves pass out to the two sides of the limbs. In all four-footed animals there is this simple arrangement of a single main nerve trunk on the dorsal and ventral side of the limb, but in mammals there are two nerve trunks on the ventral side of each limb.

In fishes a connecting nerve, which joins some of the anterior segmental nerves with the limb-stem, passes to the lumbo-sacral plexus. In some fishes, however, not only is there no connecting nerve, but even a plexus is wanting, the spinal nerve entering directly into the limb. The spinal nerves pass to and from the central nervous system, a pair between each two vertebrae. They receive their names from those of the vertebrae immediately anterior to the nerve, with the single exception of the first cervical nerve, which lies between the skull and atlas. We therefore find eight cervical nerves in the neck region, although there are only seven cervical vertebrae. The spinal nerves are then named according to the regions of the spinal column. In man there are twelve **thoracic** spinal nerves, five **lumbar,** five **sacral,** and three to five **coccygeal.**

THE SYMPATHETIC NERVOUS SYSTEM

There is a great variation in the sympathetic system of various vertebrates. The reason for such variation may be accounted for by the differences of the action and function in the different groups of animals, for it is the sympathetic nervous system which is not under the control of the will, but whose work is the regulation or control, either direct or indirect, of the internal organs, glands, blood vessels, respiratory and reproductive organs. This control is brought about by either stimulating or inhibiting the smooth muscle cells in the walls of the blood vessels, so that by the enlargement of the contraction of the blood vessels a greater or a lesser amount of blood may be supplied to any part. It is also of interest to know that the sympathetic nervous system contains sensory fibers, although when these are stimulated, consciousness of such stimulation does not result.

The sympathetic nervous system is connected with the spinal nerves by the visceral rami. The method of their development has already been discussed in embryology, which should be reviewed at this point (Fig. 337).

In some of the higher groups of animals, large plexuses are formed in the more important and vital body regions. These have received the special names of **cardiac, pelvic,** and **hypogastric** ganglia, while the large one in the abdominal region is known as the **solar plexus.**

There is usually a longitudinal sympathetic trunk connecting the chain ganglia of each side, though in the lampreys the chain ganglia are not connected with each other at all, and the sympathetic system is confined entirely to the body cavity, while in slightly higher groups there may be extensions from one to the other ganglion.

Besides the visceral sensory and motor elements which we have been discussing in the sympathetic system, the visceral rami also carry fibers which arise in the ganglion cells of the dorsal ganglion or in the lateral column of the cord itself (Fig. 492). As their axones and dendrites develop, they interlace with both motor and sensory ganglion cells lying in the chain ganglia. Nerve fibers from these then extend out to the viscera, while others run backward in the dorsal and ventral rami of the spinal nerves to reach blood vessels and smooth muscle fibers in the more peripheral regions of the body. These are purely sympathetic fibers, and, as they are non-medullated, they are gray in color, so that the trunk carrying these gray fibers from the chain ganglion to the dorsal and ventral branches is called the gray ramus.

It is important for future work to know that some of the cells from the spinal cord or spinal ganglia of the dorsal root migrate to various parts of the body, and are usually quite closely **associated with the glands of internal secretion,** such as the **hypophysis, carotid gland, suprarenals,** etc. These cells have a **peculiar affinity for chromic acid salts,** and are therefore often called **chromaffine cells,** though their function is yet unknown.

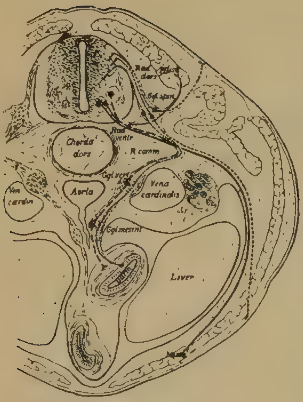


Fig. 492.

Transverse section through the body of a typical Vertebrate, showing the peripheral (segmental) nervous apparatus. *Small dots,* afferent visceral neurones; *coarse dots,* afferent somatic neurones; *dashes,* efferent visceral (ventral root and sympathetic) neurones; *lines,* efferent somatic neurones. *Darm,* gut; *Ggl. spin.,* spinal ganglion; *Ggl. vert.,* vertebral sympathetic ganglion; *Ggl. mesent.,* mesenteric sympathetic ganglion. The peripheral sympathetic ganglionic plexuses (Auerbach and Meissner) are not shown. *Musc.,* muscle; *Rad. dors.,* dorsal root; *Rad. vent.,* ventral root; *R. comm.,* white ramus communicans. Two sympathetic neurones are represented as intercalated in the visceral efferent pathway. It is doubtful if there should be more than one. (After Froriep.)

THE CRANIAL NERVES

In the early part of our work, we found that the frog has ten cranial nerves, and that mammals have twelve. The cranial nerves differ from the spinal in not being truly segmental nerves (Fig. 493), and in some of them being purely sensory, some purely motor, and still others of a mixed nature. Besides, the cranial nerves which carry sensory fibers all have a ganglion near the root, while those of a pure motor nature do not have.

They are like the spinal nerves in so far as some of them have somatic sensory, somatic motor, visceral sensory, and visceral motor fibers, but are unlike the spinal nerves in that two additional components occur in connection with the cranial nerves. These are the nerves of special sense, and in the fishes, the nerves of the lateral line (Figs. 340, 479).

The somatic sensory nerves in the head are called **general cutaneous** nerves. They terminate in the skin either as free nerve ends or as special sense organs of touch. The visceral sensory fibers end in taste organs, usually inside the mouth, but in some of the teleostomes they are distributed over the surface of the body. The termination of the elements going to make up the lateral line arrangements are sensory, and terminate in little collections of sense cells commonly called "hillocks" or **neuromasts** in the ear and in the lateral line organs of certain groups of fishes and amphibians.

The lateral line organs have been thoroughly discussed in the embryology of the frog.

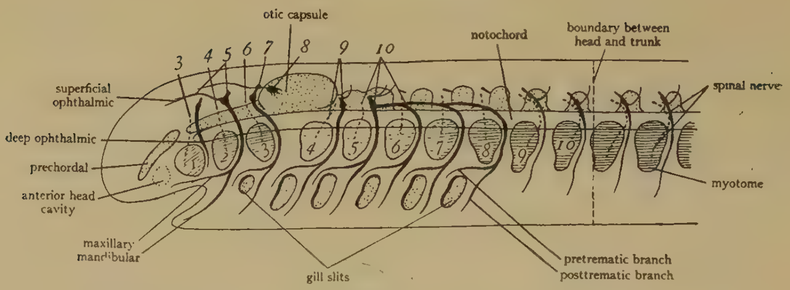


Fig. 493.

Diagram to illustrate the segmentation of the vertebrate head and the relation of the cranial nerves to the segmentation. The numbers above the figure designate the cranial nerves; the numbers in the figure are situated on the head myotomes; the sensory part of the nerves is represented by heavy continuous lines; the motor part by broken lines. The anterior head cavity is the first myotome and therefore the myotome which is numbered 1 is really the second myotome, and so on; But as the myotomes were numbered before the anterior head cavity was discovered, the old numbers are generally retained. The myotomes numbered 1, 2, and 3 produce the eye muscle; those numbered 4, 5, and 6 degenerate in the majority of vertebrates; those from 7 on probably contribute to the tongue musculature but never from typical parietal muscles, such as occur in the trunk. It is seen from the figure that the third cranial nerve and the deep ophthalmic branch of the fifth belong to the first (really second) head segment; the fourth and remainder of the fifth to the second (third) segment; the sixth and seventh to the third (fourth) segment; the ninth to the fourth (fifth) segment; and the tenth to the fifth to eighth (sixth to ninth) segments. The gill slits are intersegmental in location. The relation of the cranial nerves to the gill slits should also be noted. (From Hyman after Goodrich.)

From their functions the cranial nerves may be divided into four groups:

I. Nerves of **special sense,** namely, the **olfactory and optic.** These arise in the primitive fore-brain, the olfactory passing to the nose and the optic to the eye.

II. Nerves of the **eye muscles** (Fig. 494), namely, the **oculomotor, trochlear,** and **abducens.** These are of the somatic motor type, with a few visceral motor and sensory fibers in the oculomotor. They control the muscles of the eye. It is well to mention the **hypoglossus** at this point, as it belongs to the purely somatic motor group, the spinal accessory being of the visceral motor type.

III. The **acustico-lateralis system,** namely, the **acoustic nerve,** and those portions of the **seventh, ninth,** and **tenth** cranial nerves which are connected with the sense organs of the lateral line in the gill-breathing fish and amphibians. These nerves have a separate center in the upper anterior end of the medulla oblongata.

IV. The **fifth, seventh, ninth** and **tenth** cranial nerves are more like the spinal nerves than any of the preceding. They all arise in the medulla, each having a dorsal root and a ganglion, and each containing somatic sensory (general cutaneous) and visceral sensory and visceral motor fibers. The seventh and tenth may also include some of the fibers running to the lateral line. The ninth nerve is the simplest of these, and arises from the dorsal side of the medulla, dividing just behind its ganglion into two branches, one, the **pre-trematic** (Fig. 482), which passes in front of the gill cleft, and the other, the **post-trematic,** which passes behind that opening. The seventh nerve is arranged in a manner quite similar to that of the ninth, the spiracle being a reduced gill cleft. The fifth nerve, which is also divided in the same way, has its **post-trematic,** called the **maxillary,** and the **pre-trematic** branch, the **mandibular,** the mouth forming the opening about which this nerve divides. The **tenth** or **vagus** nerve supplies all of the remaining gill clefts and is therefore supposed to be complex, composed of as many nerves as there are clefts behind the first; however, there is no embryological evidence of distinct roots and ganglia.

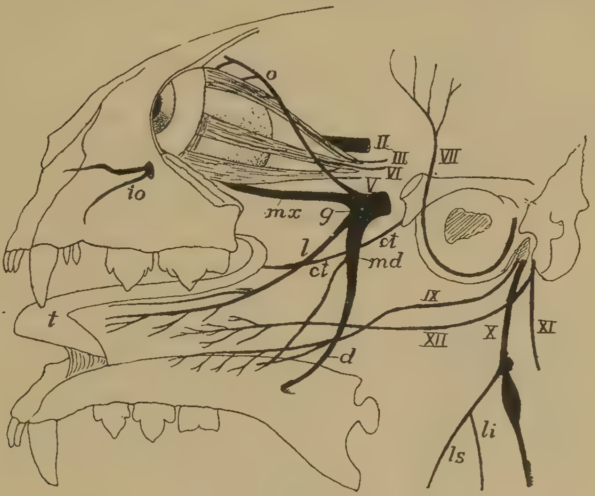


Fig. 494.

Diagram showing cranial nerves of a cat with the lower jaw reflected. *II-XII*, cranial nerves; *ct.*, chorda tympani; *d*, dentary nerve; *g*, Gasserian ganglion; *io.*, infraorbital nerve; *l*, lingual nerve; *li.ls.*, laryngeus inferior and superior; *md*, mandibularis nerve; *mx.*, maxillaris nerve; *o.*, ophthalmic nerve; *t.*, tongue. (From Kingsley after Mivart).

The cranial nerves are of considerable importance in all physiological, neurological and pathological work, so it is important that they be thoroughly studied.

I. **The Olfactory Nerve** connects the olfactory lobe of the brain with the sensory epithelium of the nose. It is different from all other cranial nerves in that it consists of many tiny prolongations of the sensory cells themselves, and in having no ganglion separate from these cells. The true olfactory nerve consists of these tiny fibers or threads, extending from the olfactory epithelium in the nose to the so-called mitral cells in the olfactory lobe. The places where the dendrites of the mitral cells meet with the terminations of the olfactory fibers from the olfactory epithelium are known as **glomeruli.** In the dogfish, for example, and in many fish, snakes, lizards, and mammals, the true olfactory nerve is very short, but the olfactory lobe is drawn out (Fig. 478), while the distal end of the lobe is enlarged into an olfactory bulb containing the glomeruli, extending proximally from this slender olfactory tract. In these cases, the olfactory bulb lies very close to the olfactory epithelium.

In some fishes, amphibia, lizards, and turtles, the nerve is long, while the olfactory lobe is shortened.

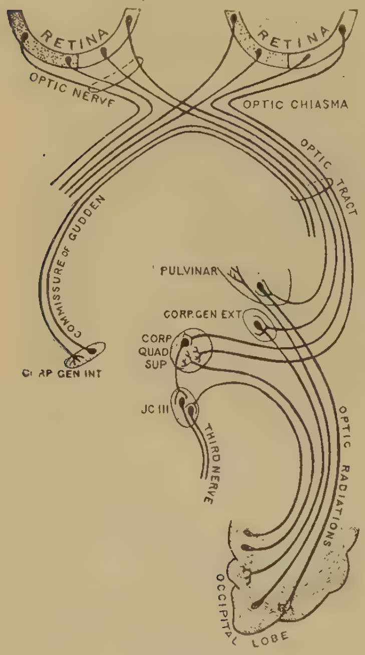


Fig. 495.

Diagram of the central connections of the optic nerve and optic tract to show crossing of the fibers. (From Cunningham's Anatomy.)

It has recently also been found that in all vertebrates there is a **terminal nerve**, sometimes called the preoptic nerve, which leaves the brain near the base of the olfactory nerve. It has a ganglion upon it but its functions and connections are as yet unknown.

II. **The Optic Nerve.** This arises in the eye and extends to the floor of the diencephalon. Branches from it are distributed over the entire inner surface of the retina, the ganglion cells lying in the inner layer. A fiber from the right eye passes to the left side of the brain, and those from the left eye to the right side of the brain (Fig. 495). The crossing of the fibers forms what is called the **optic chiasma.** The fibers, after crossing, extend dorsally and backward into the optic lobe. The optic chiasma is imbedded in the brain of cyclostomes. In other vertebrates it may be plainly seen from the outside. In mammals the crossing in the chiasma is incomplete, some of the fibers not crossing. A clear understanding of the growth and development of both olfactory and optic nerves can only be had from an understanding of their embryological development.

There is also a small thalamic nerve which arises between the diencephalon and the mesencephalon. This has so far, however, been seen only in some embryonic fishes. It shortly disappears, and little is known of its function.

The third, fourth, and sixth nerves are the **oculo-motor, trochlear,** and **abducens nerves,** or the eye-muscle-nerves, all of which assist in moving the eye in its socket (Fig. 494). The oculo-motor nerve arises from the ventral surface of the midbrain. It supplies the superior, middle and inferior rectus, and the inferior oblique muscles (Fig. 466). The abducens arises from the inferior surface of the medulla and supplies the lateral rectus muscle. The abducens is often united with the fifth nerve close to its origin. In some very few forms it is absent.

An understanding of how these nerves come to supply the muscles they do in the way that they do can be had only from our knowledge of the manner in which these muscles originally develop. The eye muscles arise from three myotomes (Fig. 493). One of the somites forms three of the rectus muscles as well as the inferior oblique muscle, while the other two somites form only one muscle each. As the myotome therefore divides into four parts, the oculo-motor nerve is carried into each part.

The **trochlear nerve** is the only motor nerve that leaves the dorsal surface of the central nervous system. It has another peculiarity, in that it has a chiasma in the dorsal surface of the midbrain, from which its fibers extend downward to the ganglion cells of the floor of the midbrain.

The nerves of the eye muscles are the only somatic motor nerves in the head of the lower vertebrates.

V, or **Trigeminal Nerve.** The trigeminal nerve is one of the largest of the cranial nerves, and arises from the antero-lateral angle of the myelencephalon. The trigeminal nerve bears a large semilunar or **Gasserian ganglion** (Fig. 494), near its origin. This ganglion may be either just inside or just outside the skull. In all higher vertebrates the nerve divides into three main branches, known as the **ophthalmic, maxillary,** and **mandibular branches** (Fig. 494). In the lower vertebrates the maxillary and mandibular nerves may be united for some distance. In the fishes, the **ophthalmic nerve** branches, forming a **superficial** and a **profound ophthalmic nerve,** both of which are purely sensory. In the higher vertebrates, it is the profound ophthalmic nerve which alone persists.

The **superficial ophthalmic** is distributed to the skin, the top of the head, and the tip of the snout. The **profound ophthalmic** passes between the eye muscles to send branches to the eyelids and conjunctiva, and then extends to the mucous membrane of the nose. It is connected with the **ciliary ganglion** to which sympathetic fibers also run. Nerves from this ganglion are sent to the iris and to the ciliary muscles of the eye. The ciliary ganglion controls the smooth muscles of the eye.

The **superficial maxillary** nerve passes along the margin of the upper jaw, and supplies the face and the teeth. If, however, the profound ophthalmic is reduced, the maxillary nerve extends into the region which the profound ophthalmic usually supplies. In the higher vertebrates, the superior maxillary unites with the spheno-palatine ganglion, to which sympathetic fibers also pass.

The **mandibular nerve** goes to the lower jaw, passing on the outer side of Meckel's cartilage (Fig. 494). In all higher forms, where the jaws become ossified, the nerve lies within the bone. This nerve carries the motor fibers which innervate the muscles of the jaw as well as the sensory fibers supplying the lips and teeth. In the mammals it also supplies part of the face, and in some of the reptiles a branch called the **lingual nerve** is sent into the tongue. In mammals the mandibular nerve is connected with both an **otic** and a **superior maxillary ganglion,** while fibers from the sympathetic system also connect.

It is now thought that the **ophthalmic branches** of the trigeminal really form a distinct nerve, and are not parts of the trigeminus at all. The reason for this belief is that the trigeminal proper arises in the medulla, while certain fibers of the ophthalmic seem to arise in the midbrain.

The trigeminus nerve may also send a twig backward. This is called the **recurrent,** or **lateralis,** of the fifth nerve. This recurrent nerve from the fifth is only found in teleosts and passes to the dorsal side of the jaw near the dorsal fin, or, in a few fishes, it goes into the paired fins.

VII. **The Facial Nerve.** This arises just in front of the ear, in the medulla. In all higher forms than those which have lateral line organs, there is a single **geniculate ganglion** which is closely associated with the **semilunar** (Gasserian) **ganglion** of the fifth in the fishes and the amphibians. The facial nerve gives off a **palatine** branch running to the roof of the mouth, where it divides into a **pre-trematic** nerve, as already stated, which enters the lower jaw, and a **post-trematic branch** called the **hyoid nerve.** The hyoid in man is called the **facial nerve,** and in all the higher vertebrates a small twig called the **chorda tympani** (Fig. 494) leaves the hyoid and unites with the mandibular branch of the fifth nerve, after which its fibers enter the lingual branch of the fifth nerve, and go to the taste organs at the tip of the tongue. The remaining portion of the facial nerve is almost entirely motor in function, its fibers controlling the muscles of the neck and the muscles which open the mouth. In mammals that have a large facial musculature the facial nerve is distributed to more regions of the face.

In animals having organs of the lateral line (Fig. 479), the seventh nerve has an additional ganglion immediately beyond which it divides into three branches, namely, the **superficial ophthalmic,** which usually unites with the superficial ophthalmic of the fifth cranial nerve and then supplies the lateral line organs and related structures on the top of the head dorsal to the eyes. The **buccal nerve,** which supplies the organs below the eye and along the line of the upper jaw, and the **external mandibular** nerve, complete the three branches. The latter is connected to the lateral line organs, of the operculum when this is present, or with the lower jaw.

The buccal nerve is usually quite closely associated with the maxillary nerve, while the external mandibular is closely associated with the mandibular ramus of the fifth nerve.

In all higher vertebrates, where no lateral line organs appear, there is no trace of these nerves, even in the embryo, although in the frog and other amphibia which pass through a gilled larval stage, these nerves are outlined in the development, but are lost during metamorphosis.

VIII. **Acusticus (Auditory) Nerve.** This nerve is quite closely related to the facial (Fig. 494), the two ganglia being fused, although the roots are quite distinct. The auditory nerve is entirely sensory, and has two branches, the **cochlear** and the **vestibular.** Both of these are distributed to the sensory structures of the inner ear. Because of the peculiar relations of this nerve to the ear, it is often assumed that, in higher vertebrates, this is the remains of the original lateral line system.

IX. **Glossopharyngeal Nerve.** This is the first of the cranial nerves lying posterior to the ear. It arises from the medulla close to the tenth nerve, and in amphibia, both its roots and its ganglion, called the **petrosal ganglion,** fuse with those of the vagus. In gilled vertebrates the nerve goes to the second gill cleft, there dividing into a **pre-trematic** and a **post-trematic branch.** The pre-trematic passes to the region of the hyoid arch as well as to the oral cavity. In teleosts it also passes to the pseudobranch. The larger of the two branches, the post-trematic supplies the muscles of the first cleft and sends a single branch to the taste organs, called the **lingual branch.** In amniotes, the post-trematic branch is called the **pharyngeal nerve,** and while there are no gill clefts, the distribution is practically the same as though there were.

There may be a dorsal nerve given off from the glossopharyngeal near the petrosal ganglion, which is somatic sensory in function, and supplies the skin on the upper side of the head. This is quite similar to the **auricular nerve** in mammals. In fishes and amphibia the glossopharyngeal has a connection with the fifth nerve; the connection is called **Jacobson's commissure.**

X. **Vagus** or **Pneumogastric Nerve.** This is made up of several metameric nerves. In comparative anatomy it is important to remember that in fish and amphibia this nerve differs considerably from that of the higher forms.

In all gilled vertebrates the vagus arises by a number of tiny roots, while it has two closely associated ganglia, the anterior being called the **lateralis,** and the posterior being called the **jugular.** The jugular ganglion contains both somatic and visceral sensory cells. It is from the jugular ganglion that a **branchio-intestinal** nerve arises, which sends branches to each gill cleft behind the first. In the dogfish there is an **epibranchial ganglion** on each of these branchial nerves. In the higher fishes these ganglia are fused in the main trunk. Beyond the ganglion, each branchial nerve divides into a pre-trematic and a post-trematic branch, just as does the ninth. Beyond the last cleft, the nerve-trunk continues as the **intestinal nerve,** going to the heart, stomach, and air bladder when that is present. It is for this reason that the nerve is called **pneumogastric** in human anatomy. The **lateralis part** of the nerve follows the lateral line organs of the body back to the tail sometimes close underneath the skin and sometimes close to the vertebral column.

The lateralis part of the vagus nerve naturally only occurs in gilled animals or those which, like the frog, have gills in their larval stage. In these latter cases the lateral part of the vagus disappears in metamorphosis.

There is a **nodose** (knot-like) **ganglion** lying on the intestinal nerve.

In animals possessing lungs, the musculature of the lungs is also supplied by the vagus. The dorsal ramus of the lower fishes is returned as the **auricular nerve,** and this unites with the auricular branch of the ninth nerve, while **sympathetic connections** are made at various points with the vagus.

It is also important to remember that the nerve supply of an organ is considered the best test of its homology, well shown in the instance of the vagus nerve, which arises in the head region but is, nevertheless, distributed to the heart, stomach, and lungs, it being recalled, from our study of embryology that the heart, stomach, and lungs, originally form in the head region of the embryo.

XI. **The Spinal Accessory Nerve.** The eleventh and twelfth cranial nerves **occur only in the amniotes,** although in the dogfish there are twigs from the vagus which innervate the trapezius muscle, while similar conditions are found in amphibia. In the dogfish and the frog, the brain-center for the eleventh nerve is in the medulla oblongata, while in amniotes the center for this nerve lies both in the medulla and in the spinal cord; in fact, some of the more posterior rootlets that go to form the spinal accessory nerve leave the cord as far down as the seventh cervical nerve. These rootlets unite into a trunk that runs cephalad into the cranium between the dorsal and ventral roots of the spinal nerve and then leaves the skull close to the vagus.

The spinal accessory is motor in function, and supplies the trapezius and sternocleidomastoideus muscles which move the shoulder girdle.

XII. **The Hypoglossal Nerve.** This is also a purely motor nerve, although during embryological development, ganglia do appear on the dorsal roots in some mammals, but all these disappear again. The rootlets of the nerve are only two or three in number, although there may be more. These unite to form the hypoglossal nerve. The hypoglossal nerve and the more anterior nerves then unite to form the **cervical plexus.** It is from this plexus that the main trunk goes to the hypoglossal muscles as well as to the retractors of the tongue, and, in birds, to the syrinx.

Small **occipital nerves** leave the skull immediately behind the vagus in many fishes. They pass backward and dorsal to the gill clefts and go forward to supply the muscles at the posterior portion of the head, and the muscles of the pectoral fin. It may be that these occipital nerves are homologues of the amniote hypoglossus.

PRONOUNCING-INDEX-GLOSSARY

TABLE OF PREFIXES AND SUFFIXES

(To be Memorized)

The object of this Index-Glossary is not to furnish a detailed explanation. This must be sought in the text on the page assigned. The object is to give the student such knowledge of the technical words used in Biology as will enable him to take apart the words he finds in his scientific reading and analyze them. Therefore, he must learn all of the immediately following prefixes and suffixes:

A or an (G. prefix, without) e.g. apoda, i.e. without feet.

Ab (L. prefix, away from) e.g. aboral, i.e. away from the mouth.

Ad (L. prefix, toward, upon) e.g. adrenal, i.e. upon the renal gland.

ae plural-ending for Latin singular nouns ending in A.

Ambi (L. prefix, both) e.g. ambidextrous, i.e. ability to use both hands.

Amphi (G. prefix, on both sides) e.g. amphibia, i.e. to live on land and in water.

Ante (L. prefix, before in place or time) e.g. antebrachium, i.e. placed before the arm.

Anti (G. prefix, opposite, or opposed to) e.g. antitoxin, i.e. opposing or neutralizing a toxin.

Arch (G. prefix, chief or early) e.g. archenteron, i.e. the earliest enteron or digestive tract.

Auto (G. prefix, self) e.g. auto-intoxication, i.e. poisoning produced within one's own body.

Bi (L. prefix, double) e.g. bilateral, i.e. same on both sides.

Blast (G. either prefix or suffix, a sprout, or bud), e.g. blastoderm, and neuroblast, i.e. a primitive germ-layer and a primitive nerve cell.

Brevis (L. short) e.g. adductor brevis, i.e. the short adductor.

Caudad (L. tail) used only in an adverbial sense, as growing caudad, i.e. tailward, or toward the tail.

Cephalad (G. head) used only in an adverbial sense, as growing toward the head.

Chondro (G. gristle or cartilage) e.g. chondrocranium, i.e. that part of the cranium developing from cartilage.

Circum (L. prefix, round-about) e.g. circumoesophageal, i.e. running around the oesophagus.

Cleido (L. clavicle—key) e.g. sterno-cleido-mastoid muscle, i.e. the muscle attached to the sternum, clavicle and mastoid bones.

De (L. prefix, off) e.g. degenerate, i.e. to become inferior—to lose generative ability.

Di (G. prefix, twice) e.g. diploblastic, i.e. to remain in the two-germ-layer state.

Dorsad (L. back) used only in an adverbial sense, as toward the back.

Ecto (G. prefix, outside) e.g. ectoderm, i.e. the germ-layer lying toward the outside.

En (G. prefix, within), e.g. encephalon, i.e. brain—within the cephalon or head.

Endo (G. prefix, within), e.g. endoderm, i.e. the germ-layer lying toward the inside.

Ento—Same as Endo.

Epi (G. prefix, upon) e.g. epinephros, i.e. same as adrenal, namely, lying upon the nephridic organ.

Ex (G. prefix, without or outside) e.g. exoskeleton, i.e. having a skeleton on the outside.

form (L. suffix, shape) e.g. fusiform, i.e. shaped like a spindle.

Genetic (G. to produce) e.g. pathogenetic, i.e. to produce disease.

Hemi (G. prefix, half) e.g. hemisphere, i.e. half a sphere.

Hyper (G. prefix, above or beyond) e.g. hypertrophy, i.e. an overgrowth.

Hypo (G. prefix, under) e.g. hypoglossal, i.e. under the tongue.

Infra (L. prefix, below) e.g. infraorbital, i.e. beneath the orbit.

Inter (L. prefix, between) e.g. intercellular, i.e. between the cells.

Intra (L. prefix, within) e.g. intracellular, i.e. within the cell.

Laterad (L. side), used only in an adverbial sense, as "toward a side."

lysin (G. suffix, a loosing or dissolving) e.g. bacteriolysin, i.e. a substance which dissolves bacteria.

Macro (G. prefix, large) e.g. macrocephalon, i.e. a large head.

Major (L. greater) e.g. pectoralis major, i.e. the greater of the pectoral muscles.

Mega (G. great) e.g. megaspore, i.e. the larger of the spores.

Mesiad (G. middle), used only in an adverbial sense, as "to grow mesiad" or toward the center of the body.

Meso (G. prefix, middle) e.g. mesoderm, i.e. the middle germ-layer.

Meta (G. prefix, after) e.g. metaphase, i.e. the phase in mitosis coming after the prophases.

Micro (G. prefix, small) e.g. micro-organisms, i.e. organisms not seen by the naked eye.

Minor (L. lesser) e.g. pectoralis minor muscle, i.e. the lesser pectoral muscle.

Mono (G. prefix, alone) e.g. monogamy, i.e. marrying but one spouse.

Multi (L. prefix, many) e.g. multicolored, i.e. many-colored.

Myxo (G. prefix, slime) e.g. myxophyceae, i.e. slime-algae.

oid (G. suffix), to be added to make an adjective, e.g. odontoid, i.e. like a tooth.

Para (G. prefix, beside) e.g. parachordal, i.e. lying beside the notochord.

Peri (G. prefix, around) e.g. pericardium, i.e. around the heart.

Poly (G. prefix, many) e.g. polymorphic, i.e. many-formed.

Post (L. prefix, after) e.g. postbranchial, i.e. behind the gills.

Pre (L. prefix, before) e.g. pre-oral, i.e. before the mouth.

Pro (G. prefix, first, or early) e.g. probranchia, i.e. the first gills that form.

Pseudo (G. prefix, false) e.g. pseudopods, i.e. false feet.

Retro (L. prefix, backward) e.g. retrolingual, i.e. backward from the tongue.

Semi (L. prefix, half) e.g. semicircular, i.e. half circle.

Sub (L. prefix, under) e.g. submandibular, i.e. under the mandible.

Supra (L. prefix, above) e.g. supratemporal, i.e. above the temporal bone.

Sur (same as supra) e.g. surangulare, i.e. above the angulare bone.

Tera (G. prefix, monster) e.g. teratology, i.e. the study of monstrosities.

Tetra (G. prefix, four) e.g. tetrapoda, i.e. four-footed animals.

Toxic (G. poison) e.g. toxemia, i.e. toxic + haemia, blood-poison.

Uni (L. prefix, one) e.g. uniramous, i.e. single branch.

Ventrad (L. belly), used only as an adverb of direction, as "to grow ventrad."

INDEX - GLOSSARY*

In all probability some of the pronunciations, as well as some of the derivations, will not meet with the approval of those who are specialists in Latin and Greek, for, often various forms of words have been used to show the student the varying forms of the same word that he will meet in scientific literature, rather than the same form throughout. Thus, for example, **meros**, thigh, and **meros**, a segment, have both been translated as though they were spelled alike. In Greek, the former has a long "e" and the latter a short "e", which really makes the words totally different.

Then too, in pronunciation, those who have learned and know a foreign language will always (and rightfully so) pronounce the word as it is pronounced in that language. This makes any definite pronunciation impossible, at least to the exclusion of other pronunciations.

Englishmen learn an anglicised Latin pronunciation, while Continental Europeans and Americans pronounce their "a" as in lark, "e" as the "a" in lake, and "i" as the "e" in see.

Dictionaries have sometimes used one method and sometimes another. The European is likely to pronounce "c" in such words as **cephalon** as "k", though in America this is not customary, but is sometimes heard.

Not each and every artery, vein, and nerve has been listed separately, as these appear under the more general headings of "Circulatory System" and "Nervous System," but one of a name has been listed so as to show the manner of usage of the definitive word. The same word is often used in different senses. The references cited have been chosen to make these different meanings clear.

If the page number is in italics, the word indexed is to be looked for **under the illustration** on the page assigned.

Lastly, as this book is written solely for the student, we have used everything which would make matters clearer to him. Therefore, although generally using a consistent marking for the pronunciation, we have also brought in a type of marking which he will find in some of the books, and it is well that he be familiar with it. Such is the case, for instance, in **tiu′ni kay′tah,** for **tū′ni kā′tâ,** as it is generally given.

KEY TO PRONUNCIATION.

ā—as in fate.
ă—as in fat.
â—as in far.
ē—as in he.
ĕ—as in hen.
ê—as in her.
ī—as in pine.
ĭ—as in pin.
ō—as in go.
ŏ—as in not.
ô—as in form.
oi—as in toy.
ow—as in cow.
ū—as in pure.
ŭ—as in nut.
û—as in French u.

KEY TO DERIVATIONS.

Ar.—Arabian.
A. S.—Anglo-Saxon.
F.—French.
Gael.—Gaelic.
Ger.—German.
G.—Greek.
Hind.—Hindustani.
Icel.—Icelandic.
It.—Italian.
L.—Latin.
L. L.—Late Latin.
M. D.—Middle Dutch.
M. E.—Middle English.
M. L.—Middle Latin.
N. L.—New Latin.
O. F.—Old French.
O. H. G.—Old High German.
P.—Portuguese.
Sp.—Spanish.
Sw.—Swedish.

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* As there is considerable variation in usage when foreign words are pronounced, such pronunciation has been chosen as seemed consistent with the best usage of the language from which the word was taken, as well as from international usage. Consequently, many words are as yet not authoritatively defined as to pronunciation and exact derivation.

It is hoped these may be added in a future edition of this book. The author will, therefore, consider it a favor to receive any and all suggestions which may be of help.

ABDOMEN, abdō'men (L. *abdomen*, belly).

Abdominal cavity 47

Abdominal vein 48

ABDUCENS, abdu'sĕns (L. *abducere*, to draw away from).............. 68

ABDUCTOR, ăbdŭc'tōr (L. *abducere*, to draw away from), definition of.. 78

ABIOGENESIS, a"biogen'esis (G. *a*, without +*bios*, life+*genesis*, beginning). The production of life from non-living matter 406

ABOMASUM, abomā'sum (L. *ab*, without+*omasum*, bullock's tripe), definition of 745

ABORAL, ăbō'ral L. *ab*, without + *os*, mouth) 254
Situated at the end opposite the mouth.

ABSORPTION, absorp'shun (L. *a*, from +*sorbere*, to suck up)........ 30
Condensation of gases on the surface of solids.
Tissue, definition of 234

ABSTRACT IDEAS, ăb'stract īde'as (L. *ab*, from + *traho*, to draw away), definition of 182

ACANTHOCEPHALA, akanthōsef'alâ (G. *akantha*, a spine + *kephale*, the head) 424, 432
An order of worm-like parasites with no mouth or alimentary canal, which attach themselves to their host by means of a hooked proboscis.

ACANTHOCEPHALUS (singular of Acanthocephala), definition of.....306

ACANTHOCHEILONEMA PERSTANS, akan'thōkilo'nema pĕrstâns (G. *akantha*, spine + *cheilos*, Lip. + L. *perstare*, persist) 303

ACANTHOPTERYGII, ..akan"thopterij'ii (G. *akantha*, a spine + *pteros*, wing or fin).......................645
A group of fishes, including the perch, bass, swordfish, etc.

ACARINA, akarī'nâ (G. *akari*, a kind of mite bred in wax)...........350, 422
An order of *Arachnida*, including the mites, ticks, etc., the head, thorax, and abdomen appearing to be one.

ACCESSORY CHROMOSOMES, akses'ōry krō'mōsōmes, definition of.*100*, 168

ACCESSORY CLEAVAGE, definition of 448

ACCESSORY REPRODUCTIVE ORGANS 439

ACCOMMODATION OF EYE, definition of 874

ACETABULUM, asetăb'ulŭm (L. *acetabulum*, a vinegar cup), the socket for the head of the femur.......... *76*

ACETABULUM, homologue of.......704

ACETABULUM OF WORMS.........*292*

ACHILLES, tendon of............*80*, 85

ACICULAE, asîk'ŭla (L. *acus*, a needle), definition of.................283

ACID GLAND *363*

ACINOUS GLAND, ăs'înôs (L. *acinus*, a grape) *673*

ACIPENSER STURIO, asipen'ser stŭ'riō (G. *akkipesios*, the sturgeon. (See sturgeon) *643*

ACOELOMATA, āsē'lŏmātâ (G. *a* without + *koilos*, a hollow tube), definition of 258

ACONITE, akō'nit (L. *aconitum*, the poisonous plant *Wolf's-bane*). *The Wolf's bane* 237

ACOUSTIC, ākoo'stic (G. *akoustikon*, pertaining to hearing)............885
Pertaining to sound.

ACQUIRED CHARACTERISTICS ...403
Characters produced during the lifetime of an individual.

ACRIDIIDAE, akridī'îdē (G. *akris*, a locust), definition of...............351

ACRODONT, ak'rōdont (G. *akros*, at the edge + *odont*, tooth), definition of 733

ACROMION, akrō'mion (G. *akromia*, the point of the shoulder blade)....*701*
The distal end of the spine of the scapula or shoulder blade.

ACTINIARIA, ăktînia'riâ (G. *actin*, a ray) 257, 420
A division of *Actinôzoa*, including the sea-anemones; approximately the *Malacodermata*.

ACTINOMMA, ăktinŏm'a, (a ray + *omma*, the eye), definition of.......148

ACTINOMYCES BOVIS, ăktĭnōmisez bō'vis (G. *actin*, a ray + *mykes*, a mushroom; L. *Bos*, *bovis*, an ox), definition of *214*

ACTINOPHRYS, ăktînŏf'rĭs (G. *actin*, a ray + *ophrys*, brow), definition of.*148*

ACTIVATOR, ăk′tĭvātŏr (L. *ago, agere,*.. to drive). From *active*—producing action 823
ACTIVE POLE, definition of........105
ACUTIFOLIUM, ăcūtĭfōl′ĭum (L. *acuo,* sharpen + *folium,* leaves).........*216*
A species of *Sphagnum.*
ADAPTATION, ădăptā′shun (L. *adaptare,* to fit to). The adjustment to circumstances 45, 316
ADAPTIVE SPECIALIZATION......716
ADELOCHORDA, adēlōkôr′da (G. *adelos,* not evident + *chorde,* a cord), definition of................639
ADENOID, ăd′ĕnoid (G. *aden,* gland + *eidos,* shape), definition of......111
ADEQUAL, ade′qual (L. *ad,* to + *aequus,* equal) 447
Pertaining to the addition of similar forms.
ADHERENCE THEORY, ădhē′rens thē′ōry (L. *ad,* to + *haerere,* to stick), definition of 122
ADIPOSE, ăd′ipōs (L. *adeps,* fat), definition of 111
ADOLESCENCE, ădōles′ens (L. *ad ulescens,* young), definition of......620
ADORAL, ădō′ral (L. *ad,* to + *os, oris,* mouth) 155
Situated at or near the mouth.
ADRENAL BODIES, addree′nal (L. *ad,* upon; *renes,* kidneys).......... 53
ADRENALIN, ăddrĕn′ălyn 53
A crystalline substance obtained from suprarenal extract.
ADSORPTION, adsôrp′shon (L. *ad,* to + *sorptio,* sucking up)............
ADVEHENT, ad′vēhĕnt (L. *ad,* to + *vehens,* carrying).............601, 798
AEPYORNITHIFORMES, ēpĭôrnĭth′ĭfōrmēz (G. *aipys,* high, + *ornis,* bird + *forma,* form)..............425
AERATED, ā′erat (G. *aer,* air)......321
To expose to the air.
AEROBIC, āĕrō′bĭk (G. *aer,* air + *bios,* life) ....
AESTIVATION, ĕstĭvā′shôn (L. *aestivare,* to pass the summer)........262
AESTIVO-AUTUMNAL, ĕstē′voâtum′nal (L. *aestivus,* summery + *autumnalis,* belonging to autumn).......133
AFFECTIONS, ăffĕkshôns (L. *affectio,* a state of mind), definition of......174
AFFECTOR, aff′ekter (L. *afficere,* to act upon), definition of..........177
AFFERENT, aff′errent (L. ad, to; *fero,* bear) ....
AGASSIZ, a′găsee′, Jean Louis Rodolphe 380, 415
AGGLUTINATION, ăglūtĭnā′shôn (L. *agglutinare,* paste to), definition of.200
AGLOSSA, ăglo′sâ (G. *aglossos,* tongueless), definition of..........650
AIR-SACS OF INSECTS........329, 359
ALAE TEMPORALES, ālētemporā′lēs (L. *ala,* the wing, pl. *alae* + *tempora,* temples) 687
ALBERTUS MAGNUS 377
ALCYONACEA, ăl′sĭōnā′sēa 420
An order of *Alcyonaria.*
ALCYONARIA, al″siōnā′riâ (G. *alkyon,* a kingfisher)..........*256,* 420
ALEXIN, ălĕk′sĭn (G. *alexein,* to ward off), definition of.................199
ALGAE, ăl′jē (L. *alga,* seaweed; pl. *algae*), definition of..............203
ALIMENTARY CANAL, ălĭmen′tăry kănăl′ (L. *alimentarius,* pertaining to food; *canalis, channel*).........*267*
ALISMA PLANTAGOAQUATICA, alis′mâ plăntā′gōakwăt′ika (G. *alisma,* a water plant + L. *plantago,* plantain + *aquaticus,* pertaining to water) 245
ALISPHENOID, ălĭsfē′noid (L. *ala,* wing + G. *sphenoeides,* wedge-shaped) 695
ALKALINE GLAND, ăl′kălĭn or lĭn (F. *alcalin*) *361*
ALLANTOIC VESICLE, ălăntō′ĭk vesĭk′l (see allantois + L. *vesicula,* little blister), definition of...........488
ALLANTOIDA, ălăntoi′dâ (G. *allantoeides,* sausage shaped)...........663
ALLANTOIS, ălăn′tōĭs (G. *allas,* sausage; *eidos,* form)................ 65
ALLIGATOR, brain of, ăl′lĭgātēr (Sp. *El lagarto,* lizard; L. *Lacertus,* lizard) 862
ALLOGROMIA, ălōgrō′meâ 148
An order of the *Foraminifera.*
ALLOLOBOPHORA FOETIDA, ălōlōbōf′ōrā fēti′da (G. *allos,* other + *lobos,* pool + *phora,* fruit crop, + L. *foetidus,* stinking), definition of.281
ALTERNATION OF GENERATIONS IN HYDRA 251
ALTERNATION OF GENERATIONS IN INSECTS 346
ALTERNATIONS OF GENERATIONS IN PLANTS 225
ALVEOLI OF LUNG, ălvee′ohlie (L. a little cavity).................. *63*
ALVEOLUS OF TOOTH, ălvē′ōlŭs (L. *alveolus,* a small hollow), definition of 733
ALYTES OBSTETRICANS, al′ĭtēz (G. *alytos,* continuous, + *obstetricare,* to be a midwife)............*650*
AMARYLLIS, ămăril′is (G. *amaryssein,* to sparkle, or L. + G. *amarytlis,* name of shepherdess) *243*

AMBLYCORYPHA OBLONGIFOLIA, ămblîkor′ifâ (katydid), (G. *amblys*, blunt + *koryphe*, head, top, + L. *oblongus*, rather long + *folium* (pl. folia), a leaf.........................*342*
AMBLYSTOMA, amblis′tōmâ (G. *amblys*, blunt + *stoma*, mouth) *559*
AMBLYSTOMA TIGRINUM, tĭgrē′num (G. *amblystoma* + L. *tigrinus*, tiger like) *559, 648*
AMBOCEPTOR, ămbōsĕp′tŏr (L. *ambo*, both + (*re-*)*ceptor*, a receiver), definition of 199
AMEIURUS, ămĭū′rus (G. *A*, without + *meiouros*, curtailed)............*644*
AMETABOLOUS, ămĕtăb′ōlūs (G. *ametabolos*, unchangeable) 331
AMIA CALVA, ăm′iâ (G. *amia*, a kind of tunny) *643*
AMITOSIS, ămîtō′siz (G. *a*, without + *mitosis*) ....
Direct cell-division.
AMMOCOETES, ămōsē′tēz (G. *ammos*, sand + *koite*, bed).......*467, 543, 578*
The larvae of the Lamprey.
AMNIO-CARDIAC VESICLES, ămnîō-kâr′dîâk, definition of.............469
AMNION OF INSECT, am′neeon (G. a membrane of the embryo), definition of 346
AMNIOTA (AMNIOTES), ămnîō′tâ (see amnion), definition of........663
AMNIOTIC CAVITY, ămnîot′îk (G. *amnion*, membrane around the fetus) 623
AMNIOTIC CAVITY, false, definition of *623*
AMOEBA, ămē′bâ (G. *amoibe*, change) 121
AMPHIBIA, ămfîb′eeah (G. *amphi*, double; *bios*, life) ... 43, 425, 431
Classification of 646
AMPHIBIA—
Muscles of *830*
Skull of *694*
AMPHICOELOUS, ămfeesee′lous (G. *amphi*, double + *koilos*, hollow), definition of 683
AMPHICYON, ămfîs′îŏn (G. *amphi* + *kuon*, dog) *736*
AMPHINEURA, ămfînŭ′râ (G. *amphi*, around + *neuron*, sinew, nerve).421, 429
AMPHIOXUS, cleavage of, ăm′fîox′us (G. *amphi*, both; *oxys*, sharp).....*446*
AMPHIPLATYAN, ăm′feepla′teean (G. *amphi*, both; *platys*, êat), definition of 683
AMPHIPOD, ăm′fîpŏd (G. *amphi* + *pous* (*pod*) foot).................316
AMPHISBAENIDAE, ămfîsbē′nîdē (G. *amphisbaina*, serpent, believed to move with either end first)........417
The family of snake-like lizards.
AMPHISTYLIC, ămfĭstī′lĭk (G. *amphi* + *stulos*, pillar), definition of.....698
AMPHIUMA MEANS, ămfîū′mâ (G. *amphi*, on both sides + *pneuma*, breath) *648*
AMPHIUMIDAE, ămfîū′mīdē, definition of . (See amphiuma).........647
AMPULLA, ămpull′ah (L. flask), definition of 867
AMYGDALAE, ămig′dālē (L. *amygdala*, almond), definition of........849
AMYLOPSIN, ămylŏp′sîn (G. *amylin*, starch + *pepsis*, cooking)......... 50
ANABAS SCANDENS, ăn′ăbăs (climbing perch); (G. *anabainein*, to go up) *645*
ANACANTHINI, ăn′ăkănthī′nī (G. *ana′kanthos*, spineless) 644
ANAEMIA, ănē′mîâ (G. *anaimia*, want of blood), definition of........133, 283
ANAEROBIC, ănāērō′bîk (G. *an*= without + *aer* = air + *bios* = life), definition of 189
ANAL GLANDS, ā′năl (L. *anus* = ring + gland), definition of.......673
ANALLANTOIDA, ănălăntoi′dâ (G. *an*, without + allantois), definition of 663
ANALOGOUS, ănăl′ŏgŭs (G. *ana*, according to + *logos*, a ratio), definition of 118
ANAMNIA, anam′neeah (G. *an*, without; *amnion*, embryonic membrane), definition of 663
ANAMNIOTA. (Same as anamnia)..663
ANAPHASE, ăn′âfāz (G. *ana*, up + *phasis*, appearance).............*97*, 98
ANAPHYLACTIC SHOCK, ănăfîlăk′tîk (G. *ana*, up + *phylaktikos*, fit for preserving), definition of..........201
ANAPHYLAXIS, ănăfîlăksîs (G. *ana*, up + *phylax*, guard) 201
ANAS BOSCHAS, ā′nâs bosk′as (L. *anas*, duck) *701*
The mallard.
ANASA TRITIS (squash-bug), ***ăn′âsâ***
ANASTOMOSIS, ănăstōmōsis (G. an opening) 112, *774*
ANATOMY, ănă′tōmî (G. *ana*, up + *tome, cutting*) 30, 31
ANCHYLOSE, ăng′kîlōz (G. *angkylosis*, stiffness) 733
ANCONEUS, an′konee′us (L. *ancon*, the bend of the arm)...........*80*, 81
ANDRAE RETZII, gyrus of.........*844*
ANDREAEA PETROPHILA, ăndrēē′â (after the German botanist, Andreas) 215
ANDREAEALES, definition of.......216
ANDROECIUM (stamens), ăndrē′-shiŭm (G. *aner*, man + *oikos*, house) ***203***

ANGIOSPERMS, ăn'jĭosperms (G. *anggeion,* vessel + *sperma,* seed), definition of 227

The slow worm of Europe.

ANGLER *645*

ANGUILLA CHRYSYPA, ăngwĭl'a (L. eel) *644*

ANGUILLULA ACETI, ăngwil'ūlâ (L. diminutive of eel)................306

ANGUIS FRAGILIS, ăng'gwĭs (L. *anguis,* snake) *655*

ANGULAR CARTILAGES 617

ANGULI 79

A genus of mollusks.

ANGULO-SPLENIAL, ănggūlōsple'nial (L. *angulus,* corner + *splenium,* a patch) *72*

ANIMAL POLE, definition of....105, 439

ANIMAL PSYCHOLOGY 172-184

ANKYLOSTOMA DUODENALE, ănkĭlōs'tōmâ (G. *ankulos,* crooked + *stoma,* mouth) 303

ANKYLOSTOMIASIS, ănk'ilōstōmī'âsis 303

The disease caused by Ankylostoma.

ANLAGE, ânlâ'gê (Ger. *anliegen,* to lie on) 458

ANNELIDA, ănel'ĭda (L. *annulus,* ring + G. *eidos,* resemblance)......264, 528

ANNUAL PLANTS, ăn'ūal plănts (L. *annus,* year + *planta,* a plant)....232

ANNULAR TUBES, ănūlar tūbs, (L. *annulus,* ring + tubus, water pipe), definition of 234

ANNULATA, ănūlā'tâ (G. *anulus,* a ring), definition of................264

ANNULI, definition of..............264

ANNULUS FINGER, definition of....710

ANNULUS OF VIEUSSENS.......... *65*

ANNULUS TYMPANICUS, definition of 616

ANOLIS PRINCIPALUS, ănō'lis (a native name in the Antilles).......*655*

ANOPHELES, ănŏf'ĕlēs (G. *anopheles,* hurtful) 133, 137

ANOPHELES MACULIPENNIS *335*

ANSERIFORMES, an'sĕrĭfôr'mēz (L. *anser,* goose + form).............425

The goose-like birds. Aquatic birds with beaks covered with a soft, sensitive membrane and edged with horny lammellae.

ANTAGONISTIC MUSCLES.....762, 828

ANTARTICULAR 697

ANT-EATERS 657

ANTEBRACHIUM, ăn'tēbrākiŭm (L. *ante,* before + brachium, arm), definition of 708

ANTENNA, anten'a (L. *antenna,* a sail-yard *313*

ANTENNULE, ăntĕn'ūle (L. *dim,* from *antenna*) *313*

ANTERIOR INTESTINAL PORTAL, antĕr'ior (L. *anterior,* preceding), definition of 467

ANTERIOR-POSTERIOR DIFFERENTIATION 265

ANTHER, ăn'thĕr (G. *anthos,* flower)

The part of the stamen which bears the pollen.

ANTHERIDIUM, antheri'diŭm (plural, antheridia); (G. *antheros,* flowering + idios, one's own, personal), definition of...............*187,* 208, 217

ANTHOMEDUSAE, ăn'thomēdū'sa (G. *anthos,* a flower + *medusa*)........419

A typical genus of the family *Anthomedusidae.*

ANTHOZOA, ănthōzō'a (G. *anthos,* flower + *zoon,* an animal).256, 420, 427

Animal plants. A former class or large group of zoophytes somewhat like modern *actinozoa.*

ANTHROPITHECUS, ănthrōpĭth'ēcŭs (G. *anthropos,* man + *pithekos,* one who plays tricks) *660*

Chimpanzee.

ANTHROPOMORPHISM, ăn'thrōpōmôr'fism (G. *anthropos,* man + *morphe,* form), definition of.......172

ANTIARCHI, ăntĭâr'ki (G. *anti,* against + *archos,* rectum).........646

A group of extinct mailed fishes.

ANTIBODY, ăn'tĭbŏd'i (G. *anti,* against + A. S. *bodig,* body), definition of 197

ANTIGEN, ăn'tĭjĕn (G. *anti,* against + *genos,* birth), definition of......199

ANTIPATHIDEA, ăntĭpăth'ĭdē (G. *antipathes,* of opposite feeling or property) 420

A family of black, sclerobasic corals, with branched fibrous axis, and soft friable coenenchyma.

ANTIPODAL CELLS, ăntĭ'pŏdăl (G. *anti,* against + *pous* (*podos*) foot), definition of 244

ANTISEPTIC, ăntĭsĕp'tĭk (G. *anti,* against + *sepsis,* putrefaction), definition of 192

ANTITOXIN, ăn'tĭtŏk'sĭn (G. *anti,* against + *toxikon,* poison for arrows), definition of.............197

ANURA, anew'rah (G. *an,* without; *oura,* tail) 425, 650

Tailless amphibia.

ANUS OF FROG, ay'nus (L. ring)... 45

AORTA, āôr'tâ (G. *aorte,* to lift)... ....*54,* 775

AORTIC ARCHES, āôr'tik (G. *aorte,* the Great Artery) *59*

APE 659

APHIS MAIDIRADICIS, āfîs (doubtful origin) *372*

Plant-sucking insects.

APIDAE, ăp′idē (L. a bee)..........367

The bee family.

APIS MELLIFERA *354*

APIS NOSEMA, ă′pis (L. a bee).....*153*

APLACOPHORA, ăplâkŏf′ōrâ (G. *a*, without + *plaxma*, flat part + *phoros*, to bear)..................421

A suborder of *Amphineura*, having a spiculed, vermiform body, with foot absent or merely a groove.

APOCYNUM ANDROSAEMIFOLIUM, ăpŏs′înŭm (G. *apokunon*, a plant)..*235*

APODA, ăp′ōdâ (G. *a*, without + *pous*, foot) 425, 643, 647

APONEUROSIS, apoh′newrow′sis (G. *apo*, from + *neuron*, tendon), definition of 78, 828

APOTHECIA, ăpothē′sĭâ (G. *apo*, away + *theke*, cup)...............*205*

APPENDICITIS, ăpĕndĭsī′tēs (L. *ad*, to + *pendere*, to hang)............302

APPENDICULARIA, ăpĕndîkūla′ria (L. *ad*, to + *pendere*, to hang), definition of 639

APPENDICULAR SKELETON, ăpĕndik′ūlâr (see Appendix), definition of 73

APPENDIX VERMIFORMIS, ăpĕndîks (L. *ad* + *pendere*, to hang), definition of 728, 747

APPLICATIONS VS. PRINCIPLES.25, 32

APPOSITION IMAGE, ăp′ōzîsh′un (L. *ad*, to + *ponere*, to place), definition of 322

APTERIUM, ăp′tē′rîŭm (G. *a*, without + *pteron*, wing)..................*669*

APTERYGIFORMES, ăptĕrī′jiform′ēz (G. *a*, + *pteron*)..................425

AQUATIC, ākwă′tík (L. *aqua*, water). 223, 654

AQUATIC VERTEBRATES 663

AQUEDUCT OF SYLVIUS, ak′weduct (L. *aqua*, water; *duco*, lead)...511, 845

AQUEDUCTUS CEREBRI, ăkwĕdŭk′tŭs 845

AQUEOUS HUMOR, ā′kwĕŭs (L. *aqua*,.. water) 70, 873

AQUINAS, THOMAS, ăkwī′năs......378

ARACHNIDA, ărăk′nîda (G. *arachne*, spider) 429

ARACHNOID, arack′noid (G. *arachne*, spider) 838

ARACHNOIDEA, ărăknoid′ēa (G. *arachne*, spider + *eidos*, form.422, 430

Spiders.

ARANEAE, ără′nēa (G. *arachne*, spider) 422

An old genus of spiders.

ARANTII, duct of..................795

ARBOREAL, ârbō′rēal (L. *arbor*, tree)654

ARCELLA, ârsĕl′â (N. L. diminutive of *arca*, little box), definition of....147

ARCHAEN, ârkē′an (G. *archaios*, ancient) *395*

ARCHAEOPTERYX, ârkēŏp′tĕrîks (G, *archaios* + *pteryx*, wing).........671

Oldest fossil bird, having some characteristics of a reptile.

ARCHAEORNITHES, ărkēor′nīthēz (G. *archaios*, ancient + *ornis*, a bird) 425

Fossil birds of the genus *Archaeopteryx*.

ARCHEGONIA, ârkegō′nia (G. *arche*, beginning + *gonos*, offspring), definition of 215

ARCHEGONIOPHORES, ârkēgōniŏf′ōrēz (G. *arche*, beginning + *gonos*, offspring + *pherein*, bear), definition of 218

ARCHENTERON, arken′teron (G. *archos*, chief, first; *enteron*, intestine), definition of 107

ARCHEOLOGY 32

ARCHES, VISCERAL, definition of..585

ARCHESPORE, âr′kēspōr (G. *arche*, beginning + *sporos*, seed......239, 243

(Spore-mother-cell.)

ARCHIANNELIDA, ârkianĕl′îda (G. *archi*, first + *annulus*, a ring).... ....283, 420, 428

A subclass of annelida, supposed to be the nearest living relatives of the archetypal segmented worms.

ARCHIMEDES, ârkîmē′dēs 24, 25

ARCHINEPHRIC DUCT, ârkînef′rîk (G. *archi*, first + *nephros*, the kidney) 207, 208

ARCHIPALLIUM, âr′kipal′îŭm (G. *archi*, first + L. *pallium*, mantle), definition of 843, 848

ARCHOPLASMIC, ârkōplăs′mîk (G. *archon*, ruler + *plasma*, something moulded), definition of............ 91

ARCUALIA, ar′kiuale′eeah (L. *arcus*, bow) 716

AREA OPACA, ā′rēa ōpā′kâ (L. *area*, ground space), definition of.......439

AREA PELLUCIDA, definition of....439

AREA VASCULOSA, definition of....467

AREA VITELLINA, definition of....467

AREOLAR, ărē′olar (L. *areola*, small space) 110

ARISTOLOCHIA SIPHO, ăr′îstōlō′kîâ (G. *aristos*, best + *locheia*, childbirth) *231*

The common Dutchman's pipe.

ARISTOTLE, ărĭstŏt′al 376, 388

ARMADILLO, ârmadĭl′ō (from armed)659

ARMOURED FISHES, definition of..676

AROMATIC COMPOUNDS (L. *aromaticus*, having a spicy odor)..... 95
ARROW-WORM *308*
ARTERIES OF FROG, âr'terēz (L. *arteria*, artery) 53-60
ARTERIES, SOMATIC 790
ARTERIES, SPLANCHNIC 790
ARTERIES, VISCERAL 790
ARTERIOLES, ârtēriō'ls (L. *arteriola*, small artery), definition of....799
ARTHROBRANCHES, âr'thrōbrăn'kēz (G. *arthron*, a joint), definition of 321
ARTHROPLEONA, ârthrōplē'ona (G. *arthron* + *pleon*, full)............422
  An order of the class *Collembola*.
ARTHROPODA, ârthrŏ'pōdâ (G. *arthron*, joint + *pous*, foot).........................312, 374, 424
  Crayfish 312-327
  Fly 367
  Grasshopper 332
  Honeybee 353
  Insects at Large...............328
  Plankton 325
  Terrestrial crustaceans 326
ARTICULAR PROCESSES, ărtîk'ūlâr (L. *articulus*, joint) 681
ARTICULARE, ărtîk'ūlârā 697
ARTICULATA, ărtîkūlātâ 429
ARTICULATE, ărtîk'ūlāt (L. *articulus*, joint) 73
ARTIFACT, âr'tîfakt (L. *ars*, art + *facere*, to make) *555*
  An artificial product.
ARTIFICIAL FERTILIZATION 205
ARTIODACTYLA, ârtîōdak'tîlâ (G. *artios*, equal + *daktylos*, finger)...............................426, 660
ARYTENOID, ăr'îtē'noid (G. *arytaina*, a pitcher) 762
ASCARIS LUMBRICOIDES, ăs'karis (G. an intestinal worm)...........*298*
ASCELLUS AQUATICUS, ăsĕl'ŭs (G. diminutive of *askus*, a wine skin)..326
ASCIDIACEA, asĭdia'sēa (G. *askidioy*. a wine-skin) 424, 639
  An order of tunicates.
ASCOMYCETES, ăs'kōmīsē'tez (G. *askos*, bag + *mukus*, a mushroom). 207, 209
ASCOSPORE, ăs'kôspor (G. *askos*, bag + *sporos*, seed) 188
ASCUS, ăs'kŭs (G. *askos*, bladder), definition of *188*
ASEXUAL REPRODUCTION IN *VAUCHERIA* 207
ASIATIC LUNG-FLUKE 291
ASPERA, ăs'pĕrâ (L. *aspera*, rough).*149*
ASPERGILLUS FUMIGATUS, ăspĕrjîl'ŭs (L. *aspergere*, sprinkle), definition of *211*, 212
ASPIDIUM, ăspîd'îŭm (G. *aspidion*, a little shield) *224*
  A species of fern.
ASPIDOBRANCHIA, ăs'pîdōbrang'kîâ (G. *aspis*, shield + *branchia*, gills).421
  A group of *Gastropods*.
ASSIMILATING TISSUES, ăsîm'îlating (L. *ad*, to + *similis*, like).....236
  Conversion into protoplasm of ingested nutrient material.
ASSIMILATION 30, 63
ASSOCIATION MEMORY, definition of 66, 178
ASTACUS FLUVIATALIS, ăs'tâkŭs (G. a crayfish) *313*
ASTEROIDEA, ăstēroi'dēâ (G. *asteroeides*, star-like) 420, 428
  An order of *Echinoderms*, the Starfishes.
ASTRAGALUS, asstrag'alus (G. an ankle bone) *76*, 709
ATAVISM, ăt'ăvĭzm (L. *atavus*, ancestor) ....
  Reversion to an ancestral type.
  Recurrence of a characteristic of a remote ancestor.
ATHECAE, ăthē'kē (G. without a carapace), definition of...........652
ATLAS (G. *atlas*, a giant).......*72*, 684
ATRIAL, ā'trîăl (L. *atrium*, a central room), definition of 530
ATRIOPORE, ā'trîôpore (L. *atrium* + *porus*, channel) 752
  The opening from the atrial cavity to the exterior in *Cephalopods*.
ATRIO-VENTRICULAR CANAL, definition of 530
ATRIUM, ay'treeum (L. a court)—
  Of Amphioxus 752
  Of heart 778
  Of lungs 765
  Of nose 871
ATROPHY, ăt'rôfî (G. *a*, without, *trephein*, to nourish).............316
ATTRACTION SPHERE, definition of 90
AUDITORY, aw'ditoery (L. *auditorius*, pertaining to hearing) 68
AUDITORY CAPSULES 540
  Organs of insect 337
  Pits 480
  Placodes 480
  Sac 575, 581
  Tube 869
AUERBACH'S PLEXUS *879*
AURICLE, aw'reekal (L. *auricula*, a little ear) 55, 778
AUTOGENOUS, ôtŏ'jenus (G. *autos*, self + *genesis*, birth), definition of.140
AUTOMATIC MUSCLES, definition of.112
AUTOSTYLIC, ôt'ôstī'lik (G. *autos*, self + *stylos*, pillar), definition of.698

AUTOTROPHIC, ôt′ôtrŏf′ik (G. *autos*, self + *trephein*, to nourish) ....

AVES, ay′veez (birds) 425, 431, 656

AVICULARIA, ăvĭkūlā′riâ (G. *avicula*, diminutive of bird) *309*

AWARENESS, definition of.........174

AXIALITY ....
The growth along a definite axis.

AXIAL SKELETON, definition of.... 73

AXIAL THICKENING, definition of..538

AXIL, ăk′sil (L. *axilla*, arm-pit) .*203*, 217

AXILLA, axill′ah (L. *axilla*, a little axis) *831*

AXILLARY, ăk′sĭlărĭ (L. *axilla*) .*203*, 792
Pertaining to axil; growing in the axil, or pertaining to the arm-pit.

AXIOM (L. *axioma*, a self-evident proposition) 88

AXIS, definition of..................684

AXIS CYLINDER 114
The central tract of a nerve fiber.

AXIS OF EGG.....................553

AXOLOTL, ăk′sōlŏtl *554*, *648*
A Mexican tailed amphibian which remains in the larval state.

AXON, ăk′son (G. *axon*, axle) 68
The axis-cylinder process of a multipolar nerve-cell.

AZYGOUS, az′eegos (G. *a*, without; *zygon*, yoke) 698, 797

BACILLUS, băsĭl′us (L. *bacillum*, a small stick) 190
Rod-shaped bacteria.

BACKGROUNDS 157

BACON, ROGER 378

BACTERIA, băktē′ria (G. *bacterion*, rod), definition of 190
rate of increase 192

BACTERIOTROPIN, băktēr′iōtrō′pĭn, definition of 200

BACTERIUM ACTINOCLADOTHRIX, băktē′rĭŭm ăk′tĭnōklăd′ōthrĭks (G. *aktis*, ray + *klados*, branch + *thrix*, hair) *214*

BALAENA MYSTECETUS, bălē′na (L. *balaena*, whale)................*662*

BALANCING ORGAN, definition of..323

BALANOGLOSSUS CLAVIGERUS, bahl′anohgloss′us (G. *balanos*, acorn + *glossa*, tongue)...........*546*

BALANTIDIUM COLI, bălăntĭd′ĭŭm (G. *balantidium*, a little bag) *144*

BALEEN, bălēn′ (L. *balaena*, whale), definition of 737

BALEEN WHALES 663

BARBERRY, bâr′bĕr′ĭ (M. L. *barbaris*, berry) *243*
A shrub whose ill-smelling flowers produce red berries of a pleasantly acid flavor.

BARBS (L. *barba*, beard)...........671
Thread-like structures.

BARBULES, bâr′būls) (L. diminutive of *barba*) 670

BARK, definition of 231

BASAL, bā′săl, at or near the base...218

BASAL DISC 248

BASALE, băsā′le, băsâ′lā (L. *basis*, base) 699

BASAL GANGLION, definition of....848

BASAL PLATE, definition of........615

BASCANION ANTHONYI STEJNEGER, bāskā′nĭŏn 416
A genus of snakes, such as the blacksnake.

BASIDIOMYCETES, băsĭd′ĭomīcē′tēs (G. *basis* + *mukus*, fungus) ..*207*, 209

BASIDIUM, băsĭd′ium (G. *basis*, base) *207*
A special cell of certain fungi forming spores by abstriction.

BASI-HYAL, bā′sĭhī′al (G. *basis* + *hyoeides*, y-shaped) 738

BASILAR PLATE, băs′ilar, definition of 540

BASIOCCIPITAL, bā′sĭŏksĭp′ĭtăl (L. *basis* + *occiput*, back of head) 73

BASIPODITE, băsĭp′ŏdīte (G. *basis* + *pous*, foot), definition of..........*314*

BASLE NOMENCLATURA ANATOMICA, bâl nōmĕnklâtū′râ...........416

BAST (A. S. *baest*, bast), definition of 230

BATESON, PROFESSOR........388, 679

BATOIDEA, bă′toi′dē′ă (L. *batus*, a genus of fishes)..............424, 642
A sub-order of *Plagiostomes* having ventral gill-openings.

BDELLOSTOMA DOMBEYI, dĕ′lŏs′tōmâ (G. *bdella*, a leech + *stoma*, mouth); named for J. Dombey, French botanist *641*
Cyclostomes having suctorial mouths resembling those of leeches.

BDELLOSTOMA POLYTREMA (G. *poly*, many + *trema*, hole)........*713*
Myzonts having many pairs of branchial apertures.

BEE 353
  Behavior 363
  Circulatory system 357
  Classification of 367
  Digestive system 357
  Embryology of 362
  Enemies of 365
  Excretory system 359
  External appearance 354
  Gynandromorphs 366
  Internal anatomy 357
  Metamorphosis 362
  Moth 365
  Muscular system 360
  Nervous system 359
  Reproductive system 361
  Respiratory system 358
BEHAVIORISTS, definition of 173
BELON 379
BESTIARIES, bĕs′ti′ār′ēs (L. *bestiaries*, pertaining to wild beasts) 377
  Books treating of animals.
BICEPS, buy′seps (L. *bi*, two; *caput*, head) 81
BICHAT, bēshă′ 388
BICORNUUS UTERUS, bīkor′nuus (L. *bis* + *cornu*, horn) *819*
BICUSPID, bīkŭs′pid (L. *bis*, twice + *cuspis*, point) *736*
BICUSPID VALVE, definition of 786
BIDDER'S ORGAN 610, *813*, 822
BIFARIA, bīfā′rîa (L. *bis*, twice + *fari*, to speak) *155*
BILATERAL SYMMETRY (L. *bis* + *latus*, side) 247
BILE (L. *bilis*, bile) 50, 750
BILE CAPILLARIES 50
BILE DUCT, development of 589
BILHARZIA HAEMATOBIUM, bîlhâr′zēâ hēmâtōbîŭm, definition of 291
  (After T. Bilharz.) A genus of flukes or trematodes.
BINARY, bī′năry (L. *binarius*, of two), definition of 125, 129
BIOGENESIS, bī′ōjĕn′ĕsĭs (G. *bios* + life + *genesis*, birth) 406
BIOLOGICAL UNIT, definition of 88
BIOLOGY (G. *bios*, life + *logos*, discourse)—
  Chronological table of 389
  History of 375-392
  Notable men in 386
BIOMETRICS, bīōmĕt′rîks (G. *bios* + *metron*, measure) 32
BIOPLASTS bī′ōplăsts (G. *bios* + *plasma*, something moulded) 91
BIPARTIBUS UTERUS, bīpârt′îbus (L. having two parts) *819*
BIRAMOUS, bīrā′mos (L. *bis* + *ramus*, branch) 315
BIRD, definition of 656
BIRD, circulation of *785*
  Skeleton of *703*
  Urogenital organs of *821*
BISERIAL, bīsē′rîăl (L. *bis* + *series*, series), definition of 707
BISEXUAL, bīsĕk′sual (L. *bis* + *sexus*, sex) ....
BLACK-MOSSES, definition of 216
BLADDER 48
  How formed 590
BLADE 203
BLASTOCOELE, blas′toeseal (G. *blastos*, germ + *koilos*, hollow) .*106*, 446
BLASTOCYST, blăs′tōsist (G. *blastos* + *kystis*, bladder) *626*
BLASTODERM, blas′toederm (G. *blastor*, germ; *derma*, skin) *438*, 439, 449
BLASTODERMIC VESICLE, definition of 621
BLASTOMERE, blăs′tômēr (G. *blastos* + *meros*, part), definition of 105, 449
BLASTOMYCES, blăstŏm′îsēz (G. *blastos* + *mukus*, fungus) 210
BLASTOMYCETES, blăstōmīsē′tēz, definition of 210
  Plural of blastomyces.
BLASTOMYCOSIS, blăstōmīcō′sîs, definition of 211
  The disease produced by *Blastomycetes*.
BLASTOPORE, blăs′tôpor (G. *blastos*, bud + *poros*, passage) .107, 278, 452, 554
BLASTOSTYLE, blăs′tōstīl (G. *blastos* + *stylos*, pillar) *252*
BLASTULA, blas′tiulah (L. a little germ) 106, *447*
  Of Amphioxus *44*
  Of Chick *447*
  Of Frog *447*, *554*
BLATTAEFORMIA, blăt′tā′fōrmĕă (L. *blatta*, cockroach) 423
  A subclass of *Pterygogenea* having the form of a cockroach.
BLATTOIDES (L. *blatta* + *oid*), resembling a cockroach 423
  An order of *Blattaeformia*.
BLIND-WORMS, definition of 647
BLOOD CORPUSCLES OF GRASSHOPPER *339*

BLOOD-ISLANDS, definition of......467

BLOW-HOLE, definition of..........729

B. N. A. (Basle Nomenclatura Anatomica) 416

BODY-STALK, definition of..........627

BOMBINATOR IGNEUS (M. L. *bombinare,* to buzz + *igneus,* fiery.) A species of European frogs..........*700*

BONE, how it grows..........679

BONNET 382

BORDERING CELLS *236*

BORER, definition of 641

BORK (periderm) *232*

BORRADAILE 405

BOTALLI, DUCTUS *596*

BOTALLI'S LIGAMENT *785*

BOTALLUS, duct of, definition of....531

BOTANY, bŏt′any (G. *botane,* pasture)..........185-193, 202-246
  Bacteria 190
  Bryophytes 215
  Economic 32
  Flowers 242
  Fungi 208
  Pathogenic fungi 209
  Photosynthesis 186
  Plant histology 228
  Pollination 238
  Pteridophytes 223
  Spermatophytes 225
  Thallophytes 204
  Three higher groupings..........215
  Vaucheria 207
  Yeasts 188

BOT-FLY LARVAE *369*

BOTHRIOCEPHALUS LATUS, bŏth′rēōsĕf′lŭs lā′tŭs (G. *bothrion,* pit + *kephale,* head). A genus of tapeworms also called *Dibothriocephalus.*295

BOTRYOIDAL TISSUE, bŏt′rîoidal (G. *botrys,* bunch of grapes), definition of 284

BOUSINGAULT 381

BOUTON, boo′tŏn (F. *bouton,* button), definition of 355

BOVIDAE, bō′vî′dē (L. *bos* (*bov*) ox), definition of 660

BOW-FIN *643*

BOWMAN'S CAPSULE *64*

BOWMAN'S GLAND, definition of...872

BOYLE 380

BRACHETI 552

BRACHIAL, bray′keeal (L. *brachium,* arm) ....

BRACHIOPODA, brāk′îŏp′ōdâ (G. *brachium* + *pous,* foot), definition of 310, 424, 432

BRACHIUM, brāk′îŭm (L. *brachium,* arm) 67, 707

BRACHIUM PONTIS, definition of.. ....841, 859

BRACHIUM QUADRIGEMINUM, definition of 841

BRACT, brăkt (L. *bractea,* thin plate of metal) *239*

BRAIN, brān (M. E. *brayne,* brain)—
  Center 847
  Ganglia 848
  Longitudinal section of brain....*842*
  Nuclei 847
  Of Alligator *862*
  Of Man *846*, 850
  Stem 848
  Table 840-841
  Types of *844*

BRANCHIA, bran′keeah (G. *branchia,* gills), definition of 757

BRANCHIAL 724
  Clefts 498
  Rays 758

BRANCHIATA, brăngkēâ′tâ, definition of 312
  (L. *branchiatus,* having gills.)

BRANCHIOMERIC (G. *branchia* + *meros,* apart), definition of........573

BRANCHIOPODA, brăngkēŏp′ŏda ...421

BRANCHIOSAURUS SALAMANDROIDES (G. *branchia* + *saurus,* lizard) *691*
  A species of gill-breathing lizard.

BRANCHIOSTEGAL MEMBRANE, bran′keeoss′tegal (G. *branchia,* gills; *stego,* to cover)..........759

BRANCHIOSTEGITE, brăngkēŏs′tējīt (G. *branchia* + *stege,* roof)...*313*, 315

BRANCH ROOT *203*

BRAUN'S QUILLWORT *224*
  One of the Fern Allies.

BREAD MOLD 208

BREVICEPS GIBBOSUS, brĕvîsĕps gîb′bō′sŭs (L. *brevis,* short + *caput,* head + *gibbosus,* humped)..........*701*
  Genus of tailless amphibians.

BROAD LIGAMENT, definition of....817

BRONCHIA, bron′keea (G. *bronchos,* windpipe) 730

BRONCHIAL FLUKE 291

BRONCHUS, brŏng'kŭs (L. *bronchos*, windpipe) 757
BROWN 381
BROW-SPOT OF FROG 45
BRUES 418
BRUNNER 380
BRYALES, brī'ālēs (G. *bryon*, moss), definition of 216
BRYOPHYTES, brī'ōfīts (G. *bryon* + *phyton*, plant), definition of...203, 215
BRYOZOA, brī'ōzō'a (G. *bryon* + *zoon*, animal), definition of 310, 424, 432
BUBONIC PLAGUE, būbŏn'ĭk (L. *bubonicus*, buboes, i.e., swellings)....350
BUCCAL, buck'al (L. *bucca*, cheek or mouth)—
  Cavity 48
  Glands 742
  Pouch 267
BUDDING—
  In Hydra 251
  In plants 211
BUFFON, boofon' 384
BUFFONIDAE, bufŏn'ĭdē, definition of 651
  The toads.
BUFO VULGARIS, būfo *548*, *700*
  A genus of toads.
BUGULA AVICULARIS, bū'gūlâ (G. diminutive of ox tongue, *bos*, ox + *glossa*, tongue) *309*
BULBUS AORTAE, (L. *bulbus*, globular root), definition of........595
  Arteriosus 58, 471, 481
  Cordis 778
  Oculi 875
BULLER 327
BULLHEAD *644*
BUMBLE BEE 366
BUNODONT, bū'nōdŏnt (G. *bounos*, mound + *odous*, tooth)........734
BURSA, burr'sah (L. a purse)—
  Copulatrix, a genital pouch.*330*, 344
  Entiana 747
  Inguinalis ....
BURSARIA, ber'sā'ri'ā (L. *bursa*, pouch) 154
  A genus of infusoria.
BUTTERCUP *246*

CACEPUS SYSTOMA *701*
CAECA, see'kah (L. *caecus*, blind)...329
  Colic 728
  Pyloric 728
CAECILIANS, sēsĭl'ĭans (L. *caecus serpens*, a kind of lizard), definition of 647
CAECUM, see'kŭm (L. *caecus*, blind), definition of 747
CALAMICHTHYS 642
CALCANEUM, kalkay'nēŭm (L. *calx*, heel) *76*
CALCANEUS, kalkay'neeus (L. *calx*, heel) *703*, 709
CALCAR, kăl'kar (L. *calcar*, a spur). 77
CALCAREA, kal'kā'rē'ā (L. *calcarius*, pertaining to lime) 419, 427
  A sub-class of *Spongiae;* the chalk sponges, whose skeletons are made up chiefly of calcium carbonate.
CALCIFEROUS GLANDS, kălsĭf'ĕrŭs (L. *calx*, lime + *ferre*, to carry)...268
CALCIFIED, definition of 111
CALCULUS 39
CALOPTENUS FEMORA RUBRUM, the common red-legged grasshopper.*330*
CALOPTENUS ITALICUS, kăl'ŏp'tē'nŭs ĭ'tâl'ĭcŭs (G. *kalos*, beautiful + *pteros*, winged). A species of grasshopper *336*
CALOPTENUS SPRETUS, the Rocky Mountain locust, which does incalculable damage to vegetation...*329*, *347*
CALYPTRA, kălĭp'tră (G. *kalyptra*, a covering) *216*, 219
CALYX, kā'lĭks (L. *calyx*, a calyx), a cup-like portion ....
  Of flower *203*, *242*
  Of kidney *817*
CAMBARUS AFFINIS, kam'bārŭs af'fĭn'ĭs (L. *camarus*, a sea-crab + *affinis*, related to). A species of crayfish 313
  Virilis 313
CAMBIUM, kăm'bium (L. *cambium*, change) *230*, 231
  The soft tissue from which new root and bark are formed in stems and roots of shrubs and trees.
CAMPANULA HALLERI 876
CAMPER 380
CAMPODEOIDEA, kămpō'dē'oi'dēā (G. *kampe*, a caterpillar + *eidos*, like). A family of elongated insects 422, 430
CANALICULI, kănălĭk'ūlĭ (L. *canaliculus*, a small channel), definition of.112
CANCELLOUS, kăn'sĕlŭs (L. *cancellosus*, chambered), definition of....111
CANIDAE, kăn'ĭdē (L. *canis*, dog + *idae*, like) 658
  The dog-tribe, as dogs, wolves, foxes.
CANINE TEETH, kaynine' (L. *canis*, dog) *734*
CANIS FAMILIARIS, kăn'ĭs........*701*
CAPILLARY, kap'eelay'ry (L. *capillus*, hair) 60
  Attraction 37
  Definition of 849
CAPITOSAURUS, kăpĭtôsau'rŭs (L. *capito*, *large* head + *saurus*, lizard).*694*
CAPSULE, INTERNAL, of brain, definition of 849

CARAPACE, kair′apace (F. probably L. *capa*, hood) *313*

CARBOHYDRATE, kâr′bōhī′drāt (L. *carbo*, coal + G. *hydros*, water) . 51, 96

CARBON DIOXIDE, kâr′bŏn dīŏk′sīd (L. *carbo* + *di*, two + *oxys*, sharp) . 63

CARCHESIUM, kâr′kē′sîŭm (G. *karchesion*, a drinking-cup, a mast-head), definition of 155
  A genus of infusorians; the zoōids are associated in dendriform colonies.

CARCINUS MAENUS, kăr′sĭ′nŭs mē′nŭs (G. *karkinos*, crab + *maenas*, sea-fish). The edible green crab ... *327*

CARDIAC, kâr′dēeak (G. *kardia*, heart) 318
  End of stomach 49

CARDINAL VEINS (L. *cardo*, a hinge) 482

CARDO, kâr′dō (L. *cardo*, a hinge), definition of 335

CAREY, E. J. 409, 685

CARINATAE, kar′înā′tē (L. *carinatus*, keel-shaped) 656
  A sub-class of *Aves*, having a keel-shaped sternum.

CARNASSIAL TEETH, kârnăs′îăl (L. *caro*, flesh) 736
  Cutting teeth of carnivores.

CARNIVORA, kârnîv′ōrâ (L. *caro*, flesh + *vorare*, to devour) 426, 658
  Teeth of *734*, *735*

CAROTID ARCH, kârot′id (G. *karos*, stupor) *55*
  Gland *55*, 588, 743

CARPAL, kâr′păl (L. *carpus*, wrist) .. 76

CARPELLATE CONES, definition of . 238

CARPELS, kârpēlz (G. *karpos*, fruit) 227, 242

CARPOMYCETES, kârpōmīsēt′ēz (G. *karpos* + *mukus*, fungus) 208

CARPOPODITE, kârpŏp′ôdīte (L. *karpus* + G. *pous*, foot) *314*

CARPOTROPIC, kărpŏ′trŏpĭc (G. *karpos* + *tropikos*, tropic, change) ... *239*
  Pert to tropical fruit.

CARPUS, kâr′pus (L. *carpus*, wrist), definition of 708

CARYOGAMY, kărĭ′ŏgāmĕ (G. *karyon*, nut + *gametes*, spouse), definition of 147

CAST, in paleontology 398

CASTLE 388

CASUARIIFORMES 425
  Flightless terrestrial birds with very small wings and feathers with large aftershaft, such as the Cassowary or Emu.

CAT—
  Cranial nerves of *881*
  Cross section of *832*
  Muscles of 831

CATARRHINE, ka′tăr′în (G. *kata*, near + *ris*, nose), definition of 659

CATFISH, definition of *644*

CATHARINEA UNDULATA *216*
  A species of moss.

CATOSTEOMI 643

CAUDAD, kaw′dăd (L. *cauda*, tail) .. 64

CAUDA EQUINA, kawd′â ĕkwī′nâ (L. *cauda* + *equus*, horse), definition of 837

CAUDAL, kaw′dal (L. *cauda*, tail) ... 684

CAUDATE NUCLEUS 849

CAUDATUM, kawdā′tŭm 158

CAYLUXI *734*

CEBUS HYPOLENCUS *659*

CECIDOMYIA DESTRUCTOR, sĕsîd′ŏmē′a (G. *kekis*, a gall-nut + *muia*, a fly) *345*
  A genus of flies.

CECIDOMYID, sĕsîd′ŏmîd (G. *kekis* + *muia*) *345*

CECUM (same as caecum) *739*

CELL (L. *cella*, a compartment) .. 88-116
  Chemistry of 94
  Division of 96-100
  Fertilization of 104
  Inclusions and products 90
  Maturation of 100
  Membrane 90
  Mitosis, meaning of 99

CELLI 134

CELLULOSE, sĕl′ūlōs (L. *cellula*, small cell) 93

CEMENT GLAND, sēmĕnt′ (L. *caementum*, mortar) *340*

CEMENT OF TOOTH 732

CENOZOIC, sĕnŏzō′îk (G. *kainos*, new + *zoe*, life). Geologic stratum containing recent forms of life 394

CENTER—
  Brain 847
  Correlation of 847
  Nerve 115
  Of ossification *517*
  Primary 847
  Reflex 851

CENTRAL CANAL 67, 513
  Cells 447
  Nervous system of crayfish *322*
  Nervous system of frog *65*, 66
  Nervous system of honeybee *359*
  Nervous system of insect *330*

CENTROSOME, sĕn′trōsōm (G. *kentron*, a center + *soma*, body) 90

CENTROSPHERE, sĕn′trōsfēr (G. *kentron* + *sphaira*, a ball) 90

CENTRUM, sen′trum (L. center) *72*

CEPHALAD, sĕ'phâlăd, toward the head ....
CEPHALIC FLEXURE, sephal'ik (G. *kephale*, head) *478*
CEPHALOCHORDA, sĕf'alâkōr'dâ.... ....424, 430
CEPHALOCHORDATA, seph'alowchor-day'tah (G. *kephale*, head; *chorde*, string) 639
CEPHALODISCUS DODECALOPHUS, sĕfălōdĭsk'ŭs *546*
CEPHALOPODA, sĕf'ălŏp'ŏdâ (G. *kephale* + *pous*, foot)........421, 429
  A class of *Mollusca*.
CEPHALOTHORAX, sĕf'ălōthōr'ăx ...313
CERATIUM, sĕrā'shĭŭm (G. *keration*, little horn), definition of..........151
CERATODUS 765
CERATOHYAL, sĕr'ătōhī'al (G. *keros*, horn + *uoides*, U-shaped).........738
CERATOHYAL CARTILAGE 616
CERCARIA, sĕrkā'ria (G. *kerkos*, tail), definition of 290
CERCOMONAS, sĕrkŏm'ōnâs (G. *kerkos*, tail + *monas*, monad) *145*
  A genus of protozoa.
CERCUS, sĕr'kŭs (G. *kerkos*, tail).... .... *329*, 337
CEREBELLUM, sĕr'ĕbĕl'ŭm (L. *cerebrum*, brain), definition of..66, 845, *859*
CEREBRAL CORTEX, sĕr'ĕbrăl, definition of 848
CEREBRATULUS FUSCUS *307*
  Lacteus *307*
CEREBRUM, ser'ebrum (L. brain).. ....66, 839, 848
CERIANTHIDEA, sĕrĭăn'thidē'a (G. *keras*, a horn + *anthos*, a flower)..420
  An order of *Zoantharia*.
CERVICAL, ser'vikal (L. *cervix*, neck) 684
CERVIDAE, sĕr'vĭdē (L. *cervus*, a stag) 660
  A family of solid-horned ruminants, as *stag*.
CERVIX, ser'vĭks (L. *cervix*, neck)..
CESALPINO, sĕsălpī'nō 381
CESTODA, sĕstō'da (G. *kestos*, girdle + *eidos*, resemblance)....285, 420, 428
CETACEA, sētā'sēâ (G. *ketos*, whale) 426, 662
CHAETAE, GENITAL, kē'tă (G. *chaite*, hair) *265*
CHAETOGNATHA, kētŏg'nātha (G. *chaite*, bristle + *gnathos*, jaw).... ....308, 424, 432
  A group of invertebrates of uncertain position.
CHAETOPODA, kētŏp'ōdâ (G. *chaite* + *pous*, foot)......283, 420, 428, 429
  A class of *Annelida* with setae.
CHAIN REFLEX ACTION, definition of 181
CHALAZA, kălā'ză (G. *chalaza*, hail, tubercle) *244*, *438*, 439
CHALCID, kăl'sĭd (G. *chalkis*, pertaining to Chalcis, Greek city)....345
CHALONE, kăl'ōn (G. *chalāo*, I relax)
  An anti-hormone 52
CHAMAELONTES 654
CHAMELEONS, ka'mē'lēonz (G. *chamaileon*, ground or dwarf lion)....654
CHAPELLE-AUX-SAINTS SKULL...*400*
CHARADRIIFORMES, kărăd'rĭfŏr'mēz (L. *charadra*, ravine + *forma*, form) 425
  Terrestrial, arboreal, or marine plover-like birds.
CHARYBDEA MARSUPIALIS, karĭb'dīă (G. *charybdis*, *Homeric figure*, + L. *marsupium*, a pouch)..........*256*
CHELA, kē'lă (G. *chele*, claw)......*313*
CHELIPEDS, kē'lipĕds (L. *chela*, a claw + *pes*, foot)................314
CHELONE IMBRICATA (G. *chelone* + L. *imbricatus*, covered with tiles).*653*
CHELONETI, kelōn'ētĭ (G. *chelone*, a tortoise) 422
  An order of *Lipoctena*.
CHELONIA, keelow'neeah (G. *chelone*, turtle) 425, 652
  Caouana *554*
  Longicollis *719*
  Mydas *653*
CHELONIDAE, kelon'ĭdā (G. *chelone* + *eidos*, resemblance)............652
CHELYDRA SERPENTINA, kĕl'ĭdra (G. *chelydros*, amphibious serpent). *653*, *803*
CHELYDRIDAE, kĕlid'rĭdē (G. *chelydros* + *eidos*)..................652
CHELYS FIMBRIATA, kel'ĭs (G. *chelys*, a tortoise + L. *fimbria*, fringe) *683*
CHEMISTRY 34
  Analytical 36
  Of living matter 94-96
  Synthetic 36
CHEMOTROPISM, kĕmŏt'ropizm (G. *chemos*, juice + *trope*, turning)....126
CHIASMA, kaias'ma (G. cross-mark). 66
CHICK—
  Embryology of 433-543
  DEVELOPMENT BEFORE THE EGG IS LAID 435
    Blastulation 450
    Gastrulation 451
    Morula stage 449
    Oogenesis 442
    Reproductive organs of fowl....440

PRIMITIVE STREAK AND ORIGIN of MESODERM 455
  Neural plate 459
  Notochord 458
FOUR TO SIX SOMITE STAGE...465
FIRST HALF DAY 470
  Brain differentiation 472
  Lengthening of fore-gut.........475
SECOND HALF OF SECOND DAY.
  Brain 476
  Blood-corpuscle path 483
  Circulatory system 480
  Excretory system 484
  Torsion 480
EXTRA-EMBRYONIC MEMBRANES 485
  Allantois 487
  Amnion 487
  Chorion 488
  Serosa 487
  Yolk-sac 485
DEVELOPMENT OF THE THIRD DAY 489
  Circulatory system 500
  Digestive tract 492
  Liver 496
  Lungs 495
  Nervous system 490
  Optic vesicles 490
  Pancreas 497
  Thymus gland 497
  Thyroid gland. 497
  Visceral arches 498
  Visceral clefts 498
DIFFERENTIATION OF SOMITES.502
  Excretory system 503
DEVELOPMENT OF THE FOURTH DAY—
  Adrenal bodies 520
  Allantoic circulation 524
  Circulatory system 520
  Excretory system 518
  Ganglia of cranial nerves........513
  Heart 529
  Intra-embryonic circulation 526
  Nervous system 511
  Organs of special sense..........514
  Reproductive system 519
  Skeletal structure 516
  Spinal cord 513
  Veins 531
COELOM AND MESENTERIES......536
DEVELOPMENT OF THE FIFTH DAY 538
  Heart 540
  Limbs 538
  Skull 538-540
CHIGGERS, chĭĝ'ĕrs (F. *chique*, local) *350*
CHILOMONAS, kīlŏm'ōnās (G. *cheilos*, lips + *monas*, a unit)............150
CHILOPODA, kîlŏp'ōdâ (G. *cheilos*, lip + *pous*, foot) 422
  An order of *Opisthogoneata*.
CHIMAERA MONSTROSA, kimē'râ (G. *chimara*, a fabled monster).....*642*
CHIMAPHILA, kimāf'ē'lah G. *cheima*, winter + *philos*, loving)..........*234*
CHIMPANZEE, chimpan'zē (Sp. *chimpance*, a native name)............*660*
CHIRONOMIDAE, kīrōnōm'îdē, (G. *cheir*, hand + *namenin*, to manage).345
CHIRONOMUS (G. *cheironomos*, one who moves the hands)............*330*
CHIROPTERA, kīrop'tera (L. *chiropteras*, wing-handed)..........426, 658
CHIROPTERYGIA, kīrop'terîg'îa (G. *cheir*, hand + *pteron*, a wing).....707
CHITIN, kī'tin (G. *chiton*, a tunic).. 93
  A carbohydrate derivative forming the skeletons of *Arthropods*.
CHLORAGOGEN CELLS *259*
CHLOROPHYCEAE, klōrô'fī'sēē (G. *kloros*, yellowish-green + *phykos*, sea-weed) 204
CHLOROPHYL, klō'rôfil (G. *chloros*, grass green + *phyllon*, leaf)......185
  Chemical formula of............186
CHLOROPLAST, klō'rôplăst (G. *chloros* + *plastos*, moulded)..185, 204
CHLOROSIS, klōrō'sis (G. *chloros*, grass green) 303
  A peculiar form of anaemia, characterized by a green-colored skin.
CHOANA, koh'anah (G. funnel)...... ....*515*, 582, 730
CHOANAFLAGELLATA, kō'ănōflăjēlāta (G. *choane*, funnel + *flagellum*, whip) 151, 418
  Mastigophora with a contractile collar from which the single flagellum extends.
CHOLAEPUS DIDACTYLUS *659*
CHOLEDOCHUS, DUCTUS, koled'okus (G. *choledochos*, containing bile)...497
CHONDRICONTS, kônd'rîkônt's (G. *chondros*, cartilage + *kontos*, pole). 91
  Rod-shaped chondriosomes.
CHONDRIOMITES, kônd'riomites' ... 91
  Granular chondriosomes.
CHONDRIOSOMES, kôndrîôsōmz' (G. *chondros* + *soma*, body).......... 91
CHONDROCRANIUM, kon'drocray'neeum (G. *chondros*, cartilage; *kranion*, skull) 614, 687
CHONDROSTEI, kondross'tee'eye (G. *chondros*, cartilage; *osteon*, bone).. ....425, 642
CHORDATA, classification of....... ....430, 543, 639-663
  Definition of 638

CHORDA TYMPANI (G. *chorde*, a string) 884
  Tendineae 55, 778
CHORION FRONDOSUM, kō'rîŏn fron'dosum (G. *chorion*, membrane + *frondosus*, richly foliated) 630
  Laeve 630
  In insects 346
CHOROID, koh'roid (G. *chorion*, membrane) 70
  Coat of eye 873
  Plexus 512, *571*
CHROMAFFINE CELLS, krōmăf'in (G. *chroma*, color + L. *affinis*, related) 879
  Cells which turn yellow after treatment with chromic salts.
CHROMAPHILE CELLS, krōmōfîl (G. *chroma* + *philein*, to love) 822
  Same as chromaffine.
CHROMATIN, krō'matin (G. *chroma*), definition of 90
CHROMATOPHORES, krō'mătōfōrz (G. *chroma* + *pherein*, to bear) 128, 204, 667
CHROMOMERES, krō'mōmērz (G. *chroma* + *meros*, part) 89
  The chromatin granules which form chromosomes.
CHROMOSOME, krō'mōsōm (G. *chroma* + *soma*, body) 97, 159
  Accessory 168
  Double 168
  Hetertropic 168
  X 168
  Y 168
CHROMOTROPISM, krōmŏt'ropîzm (G. *chroma* + *trepein*, turn) 127
CHRONOLOGICAL TABLE OF BIOLOGICAL EVENTS 389
CHRYSOMYIA MACELLARIA 368
CHRYSOPHRYS 824
CICATRIX, sîk'ătrîks (L. *cicatrix*, a wound) *440*, 443
  In botany, the mark left after a wound is healed.
  In embryology, the blastoderm in bird and reptile eggs.
  In zoology, a small scar in place of previously attached organ.
CICONIIFORMES, sîkōn'nîfōr'mēz (L. *ciconia*, stork) 425
  Stork-like birds.
CILIA, sĭl'îâ (L. *cilium*, an eyelid) 109
CILIARY BODY OF EYE, sill'eeary (L. *cilium*, eyelid) 873
CILIATA, sĭl'ĭă'ta (L. *cilium*) 153, 419
  A sub-class of *Infusoria*.
CINCHONA CALISAYA, sînko'na kalĭsā'ēa (Sp. *Chinchon*, town in Spain + *calisaya*, name of a bark) .*231*
CINGULUM, sing'gūlŭm (L. *cingulum*, a girdle) 276
CINOSTERNIDAE, sinōster'nîdē (G. *kinein*, move + *sternon*, breast-bone + *eidos*, resemblance) 652
CINOSTERNUM ODORATUM *719*
CIONA INTESTINALIS, sī'ōnâ (G. *kion*, pillar) *554*
CIRCLE OF WILLIS, definition of 792
CIRCULATION, sĕr'kūlā'shŭn (L. *circulatio*, act of circulating) 30, 53
  Of bird *785*
  Closed 270
  Crocodile *785*
  Double 535
  Frog *54*
  Open 270
  Pulmonary 54, 56
  Systemic 53, 56
CIRCUMFERENTIAL CANAL, sĕr'kŭmfĕrĕn'shal (L. *circum*, around + *ferre*, to bear) 254
CIRCUMVALLATE, sĕr'kŭmvăl'āt (L. *circum*, around + *valla*, wall) *739*
CIRRIPEDIA, sîrîpē'dîâ (L. *cirrus*, a curl + *pes*, foot) 421
  A sub-class of *Crustacea*.
CIRRUS, sir'rus (L. *cirrus*, tuft, lock of hair) 287
CISTUDO LUTARIA, sis'tudo luta'rẹa (L. *sista*, box + *testudo*, a tortoise + *lutarius*, belonging to mud) *702*
CIVET, sîv'ĕt (P. *zabad*, froth of milk or water) *734*
CLADISTA, kladis'tă (G. *klados*, a branch + *histion*, a web) 642
CLADOPHORA, kladof'ora (G. *klados* + *phoros*, bearing) *205*
CLADOTHRIX ACTINOMYCOSES, klăd'ōthrîks (G. *klados*, branch + *thrix*, hair) *212*
CLARIAS 767
CLASPER, klăs'per (M. E. *claspen*, to hold) 707
CLASS, in classification 415
CLASSIFICATION ..31, 32, 414, 418, 432
  Of Chordata 543, 639-663
CLAUSTRUM, klôs'trum (L. *claustrum*, a bar), definition of 849
CLAVICLE, klav'ikel (L. *clavicula*, little key) 76
CLAVICULA, klav'ik'ula (L. *clavicula*) *701*
CLEAVAGE, klē'vaj (A. S. *cleofan*, to cut) 105
  Accessory 448
  Amphioxus *446*
  Frog *553*
  Gastrula 556
  Spindle 444

CLEFTS, BRANCHIAL, definition of . 498
  Gill ... 498
  Visceral ... 498
CLEITHRUM, klyth′rum (G. *kleithron,*, bar, gate) ... *701*
CLEPSIDRINA BLATTARUM, klep′sîd′rîna (G. *klepsia,* theft + *hydor,* water + L. *blatta,* a cockroach) ... *151*
CLIMBING PERCH ... *645*
CLITELLUM, klĭtel′ŭm (L. *clitellae,* a pack-saddle) ... 265
CLITORIS, kly′toriss (G. *kleio,* to close) ... *820*
CLOACA, klō-ay′kah (L. *cloaca,* sewer) ... 49
  Glands of ... 673
CLOCK, the marvelous ... 34
CLONORCHIS SINENSIS, klonor′kis sĭnĕn′sĭs (G. *klon,* branch + *orchis,* testicle) ... *301*
  A species of fluke having ramified testicles.
CLOSED CIRCULATION, definition of ... 60, 270, 781
CLOSSENDROMORPHA 422
CLUB-MOSSES (one of the Fern Allies) ... *224*
CLYPEUS, klĭp′ēŭs (L. *clypeus,* a shield) ... *335*
CLYTRA, klīt′ra (word of no meaning) ... *362*
CNEMIAL CREST, nem′ial (G. *knemis,* shin) ... *703*
CNIDOBLAST, nī′dōblăst (G. *knide,* a nettle + *blastos,* bud) ... 248
CNIDOCIL, nī′dōsĭl (G. *knide* + *cilium,* an eyelid) ... 248
COAGULATION, kōăgūlā′shun (L. *cum,* with + *agere,* to drive) ... 39, 325
COBITIS, kōbī′tĭs (G. *kobites,* gudgeon-like) ... 770
COCCI, kŏk′sī (plural of coccus) .....
COCCIDIIDEA, kŏcksĭdĭĭd′ēâ (G. *coccus* + *idea,* a picture of) ... 153, 419
  An order of *Sporozoa.*
COCCIDIUM SHUBERGI, kŏksĭd′ĭŭm ... *152,* 153
COCCUS, kŏk′ŭs (G. *kokkos,* a seed), definition of ... 190
COCCYGEO-ILIACUS ... 81
COCHLEA, kŏck′leah (G. *kochlias,* a snail) ... *866*
COCHLEARIS DUCTUS, kŏcklēā′ris . . *866*
COCOON OF EARTHWORM, kŏkoon′ (F. *cocon,* a shell) ... 276
COD ... *644*
CODES FOR CLASSIFICATION 416
COELENTERATA, sēlĕntĕrā′tâ (G. *koilos,* hollow + *enteron,* intestine) ... 247, 257, 427
  Classification of ... 255-258
  Gonionemus ... 254
  Hydra fusca ... 247
  Obelia ... 252
  Polymorphism in ... 255
COELENTERON, sēlĕn′tĕrŏn (G. *koilos* + *enteron*) ... *252*
COELIAC, see′leeak (G. *koilia,* stomach) ...
  Artery ... 791
  Axis ... 791
  Plexus ... 68
COELOM, see′loam (G. *koilos,* hollow) ... 47, 247
COELOMATA, animals possessing a coelom ... 258
  Introduction to ... 258-261
COELOMIC CIRCULATION OF EARTHWORM, sēlŏm′ĭc ... 271
COENENCHYMA, sēnĕn′kĭmâ (G. *koinos,* common + *enchein,* infuse).
  The calcified tissue of the coenosarc of *Actinozoans.*
COENOCYTE, sē′nŏsīt (G. *koinos,* common + *kytos,* hollow) *78,* 207
COENOSARC, sē′nŏsârk (G. *koinos,* common + *sarx,* flesh) ... *252*
COENURUS, sēnū′rus (G. *koinos* + *oura,* tail) ... *294*
  A metacestode with a large bladder, from the walls of which a large number of heads are formed.
COHNHEIM'S FIELDS, definition of . 114
COITION, kōĭ′shŭn (L. *coitio,* a going together) ...
  Sexual copulation.
COLCHICUM, kol′chĭkum (G. *kolchikon,* plant with poisonous bulbous roots) ... *235*
COLEOPTERA, kōleŏp′tĕrâ (G. *koleos,* sheath + *pteros,* wing) ... 423
  An order of *Coleopteroidea.*
COLEOPTEROIDEA, kōleŏpteroid′ēâ . . 423
  A sub-class of *Pterygogenea.*
COLEPS HIRTUS, kol′eps hir′tŭs (G. *koleps,* bend or hollow of knee + L. *hirtus,* stubby) ... *154*
COLLATERAL FIBROVASCULAR BUNDLES (L. *cum,* with + *latera,* sides) ... 236
COLLATERAL ORGANS OF INSECT . 337
COLLATERIAL GLAND, kolētē′rial (G. *kolletos,* from *kollan,* glue together) ... *340*
COLLECTING TUBULES 64, 505
COLLEMBOLA, kolem′bola (G. *kolla,* glue + *embolan,* peg or wedge) . 422, 430
COLLENCHYMA, kŏlĕng′kĭmă (G. *kolla,* glue + *enghyma,* infusion) . . 234

COLLICULI, kŏlĭk′ūlī (L. *colliculus*, a little hill) 840
COLLOID, kŏl′oid (G. *kolla*, glue + *eidos*, form), definition of 94
COLON, koh′lon (G. *kolon*, member) . 338
COLONIAL FORMS, living in colonies . 129
COLPIDIUM COLPODA *154*
COLPODA, kolpo′da (G. *kolpodes*, winding sinews) 154
COLUBER ANTHONYI, kol′uber (L. *coluber*, serpent) 416
COLUMBUS 378
COLUMELLA, kol′yumell′ah (L. little column) 71, 72, *215*
    Of ear *867*
    Of Frog 45
COLUMNAE CARNEAE, kolŭm′nā cârnēā (L. *columnae* + *carnis*, flesh) 778
COLUMNAR, definition of 109
COLYMBIFORMES, kōlĭm′bifōr′mēz (G. *kolymbun*, divert + form) 425
  Aquatic birds with webbed or lobed toes, feet far back and body carried upright, such as the loons and grebes.
COMMISSURE, kŏm′ĭsūr (L. *cum*, together + *mittere*, to send) *65*
    Of brain 843, 858
COMPARATIVE ANATOMY 637-886
  INTRODUCTION TO 637
  CLASSIFICATION OF CHORDATA 639-663
  INTEGUMENT 664
    Of amphibia 668
    Of birds 669
    Of fishes 668
    Of mammals 671
    Of reptiles 669
    Glands 672
    Hair 672
    Scales 675
  ENDOSKELETON 681
    Appendicular skeleton 698
    Free appendages 707
    Hip girdle 704
    Limbs 707
    Paired appendages 699
    Regions of vertebral column 684
    Skull 685
    Summary of cranium 714
    Summary of skeletal system 716
    Vertebral column 681
  DIGESTIVE SYSTEM 722
    Detail study 728
    Glands 741
    Intestine 746
    Liver 749
    Oesophagus 744
    Pancreas 751
    Pharynx 742
    Stomach 745
    Summary 751
    Teeth 731-737
    Tongue 738
  RESPIRATORY SYSTEM 757
    Air-bladder and accessory organs 767, 770
    Lungs and air-ducts 762
    Summary 766
    Swim-bladder 761
  CIRCULATORY SYSTEM 772
    Aorta and aortic arches 786
    Arteries 786
    Arteries of dorsal aorta 790
    Detail studies 776
    Development 781
    Heart 776
    Lymphatic system 799
    Somatic arteries 791
    Summary 800
    Vascular system 779
    Veins 793
    Visceral arteries 791
  UROGENITAL SYSTEM 806
    Adrenal organs 822
    Mesonephric ducts 809
    Mesonephros 807
    Metanephros 810
    Organs of copulation 821
    Oviducts 814
    Pronephros 807
    Reproductive ducts 811
    Summary 823
    Urinary bladder 810
  MUSCULAR SYSTEM 826
    Visceral muscles 829
  NERVOUS SYSTEM 833
    Brain 838
    Brain table 840-841
    Cerebellum 859
    Cerebrum 839
    Cranial nerves 879
    Diencephalon 856
    Epiphysial structures 856
    Medulla oblongata 859
    Meninges 838
    Mesencephalon 858
    Neuromeres 837
    Organs of special sense 865
    Peripheral 876
    Rhombencephalon 859
    Spinal cord 835
    Summary 860
    Sympathetic 878
    Telae chorioideae 860
COMPLEMENT, definition of 199
COMPLEMENTAL MALES 327
  A purely male form, usually small, living in close proximity to hermaphroditic forms.
COMPLETE FIBROVASCULAR BUNDLE 232
COMPLETE FLOWER 228

COMPLEX REFLEX ACTION 178
CONCENTRIC FIBROVASCULAR BUNDLES 236
CONCH, kŏnk (G. *kongche*, shell) 869
CONCHA, NASAL, kon′ka (L. shell) .*515*
CONCHOLOGIST, kōnkŏl′ōjist 418
CONCLUSIONS, definition of........182
CONCRESCENCE, kŏnkrĕs′ĕns (L. *cum*, together + *crescere*, to grow) .*452*
CONDENSATION 38
CONDUCTING TISSUES, definition of 234
  Mechanism 866
CONDUCTIVITY, kŏn′dŭktĭv′ĭtĭ (L. *conducere*, to lead together) 38
CONDYLE, kon′dill (L. *condylus*, knuckle) *72, 703*
CONE (G. *konos*, a cone) *216*, 223
CONEY 662
CONFLUENCE, kŏn′flooĕns (L. *cum*, with + *fluere*, to flow) *452*
CONGO SNAKE *648*
CONIDOSPORES, konĭd′ĭo′spore (G. *konidion*, particle of dust + spore) .*211*
CONJUGATION, kŏn′joogāshun (L. *cum*, together with + *jugare*, yoke) .*158*
CONJUNCTIVA, kon′junktie′va (L. *conjunctus*, join together) 875
CONNECTIVE TISSUE (L. *cum* + *nectere*, to bind) *49*, 109
CONSCIOUSNESS, stream of........174
CONSPICUOUSNESS VS. IMPORTANCE 32, 375
CONTINUITY, law of..........376, 406
  Physiological *150*
CONTRACTILE, kŏntrăk′tĭl (L. *cum* + *trachere*, to draw) 93, 865
  Fibrils 248
  Theory 122
CONUS ARTERIOSUS (G. *konus*, cone) 790
CONVALLARIA, konvălā′rēa (L. *convalis*, a valley enclosed on all sides) .*234*
CONVECTION, konvek′shun (L. *convehere*, convey) 38
CONVERGENT EVOLUTION, kŏnvĕr′gĕnt (L. *convergere*, to incline together) 409
CONVOLUTIONS OF BRAIN, kŏn′vôlū′shun (L. *cum*, together + *volvere*, to wind) 843
COORDINATING FACTS 40
COORDINATION OF SUBJECTS STUDIED 34
COOTS, kōōts (M. E. coote, coot) 417
COPE 388
COPEPODA, kōpĕp′ōdâ (G. *kote*, oar + *pous*, foot) 421
COPULA, kop′yulah (L. *cum*, together; *apo*, bind) 616, 740
COPULATION PATH 551
CORACIIFORMES, korā′seefor′mēz (G. *korakias*, a kind of raven + L. *forma*, shape) 425
  Arboreal roller-like birds such as swifts, kingfishers, owls, etc.
CORACO-ARCUALES, kor′akō arkūălēz (G. *korakinas*, beak like a raven + L. *arcus*, a bow) 831
  Radiales 79
CORACOID, kor′akoid (G. *korakoeides*, like a crow's beak) 75
CORALLIUM, korăl′ium (G. *korallion*, red coral) *256*
CORDS, MEDULLARY, definition of..520
  Ovarial 520
CORIUM, koh′reeum (L. leather) 665
CORK CAMBIUM (Sp. *àlcorque*, cork), definition of 231
CORM, kôrm (G. *kormus*, a trunk) ..*255*
CORNEA, kor′neeah (L. *corneus*, horny) 69, 872
CORNEUM, kōr′neeum (L. *corneus*, horny) 665
CORNICLES, kor′nĭklēz (L. *corniculum*, little horn) 372
CORNIFICATION, kor′nĭfĭkā′shun (L. *cornu*, horn + *facere*, to make) .667, 737
CORNUA, kor′niuah (L. horn) 72
COROLLA, kôrŏl′ă (L. *corona*, a crown) *203, 242*
  The petals of a flower.
CORONA RÀDIATA OF BRAIN, kôrō′nă rā′dĭâtâ 849
CORONARY VESSELS, kŏr′ŏnărĭ (L. *corona*, crown) 780
  Crown-like vessels.
CORONOID, kor′ohnoid (G. *korone*, crow) 697
CORPORA BIGEMINA, kōr′pōrâ bīgĕm′ĭnâ 839
  Quadrigemina 512
CORPUS ALBICANS, kōr′pus ăl′bĭkăns (L. *corpus*, body + *alba*, white) *863*
  Callosum *842*
  Cavernosum *820*
  Luteum 811
  Mammilare 845
  Restiforme 859
  Striatum 839, 848
CORPUSCLES, BLOOD OF GRASSHOPPER, kôr′pŭsls (L. *corpusculus*, a small body) 339
CORRELATION CENTERS, definition of 847
CORRODENTIA, kōrōdĕn′shiâ (L. *com*, together + *rodere*, gnaw).....423
  An order of *Blattaeformia.*
CORTEX, kôr′tĕks (L. *cortex*, bark) ..216
  The outer portion of an organ.
  Of brain 839
  Primary 230

CORTI, ORGAN OF 869

CORTICAL PARENCHYMA, definition of 230

COSTA, kos′tah (L. *costa*, a rib) *335*

COTYLEDON, kŏt′ĭlē′don (G. *kotyle*, a cup) *203*

COTYLOID BONE, kŏt′ĭloid (G. *kotyle* + *eidos*, form), definition of.......707

COTYLOSAURIA, kŏt′ĭlōsâ′rĭă (G. *kotyle* + *sauros*, lizard)..........*694*

COVERING TISSUES, definition of..234

COWPER'S GLAND *820*

COXA, kŏk′să (L. *coxa*, hip).........328

COXOPODITE, kŏksŏp′ŏdĭt (L. *coxa* + G. *pous*, foot)..................*314*

CRANIAL NERVES (G. *kranion*, head) 67, 68, 861

CRANIATA, krāniā′ta (G. *kranion*, the skull)..............424, 431, 543, 640
  Definition of 431

CRANIUM, krā′nium (G. *kranion*, head) 73, 686

CRAYFISH 312-327
  Adaptations 316
  Autotomy 324
  Circulatory system 318
  Crustacea 325, 326
  Digestive system 318
  Excretory system 321
  External appearance 313
  Muscular system 323
  Nervous system 321
  Parasitic crustacea 325
  Regeneration 324
  Reproductive system 323
  Respiratory system 320
  Sense organs 321
  Serial homologies 316

CREMASTER MUSCLE, krēmas′ter (G. *kremannunai*, to hang)........818

CREODONT, kre′odont (G. *kreas*, flesh +*odous*, tooth) *734*

CRESCENT, GRAY, definition of.....552

CREST (L. *cresta*, a crest) 77

CRETINISM, krē′tinizm (F. *crétinisme*, *probably* Christian)....... 53

CRICKET, krik′et (M. D. *kriecker*, creaker) *342*

CRICOID, krīk′oĭd (G. *krikos*, a ring + *eidos*, form) 762

CRINOIDEA, krinoi′dē (G. *krinon*, a lily + *eidos*, resemblance).....420, 428
  A class of *Echinodermata*, the sea lilies or feather stars.

CRISTA GALLI (L. *crista, a crest* + *gallus*, cock) *868*

CRITERIA FOR A SATISFACTORY EVOLUTIONARY THEORY 413

CROCIDURA COERULEA, krōsĭdū′râ sērū′lēă (G. *krokys*, piece of woolen cloth + L. *coeruleus*, sky-colored) .*678*

CROCODILE HEART *785*

CROCODILIA, krok′ohdill′eeah (L. crocodile)...............425, 651, 653

CRO-MAGNON MAN (Gael.-Ir. *cro*, blood, death), definition of........400

CROP (M. E. *croppe*, top of plant) 329, 744

CROSSOPTERYGII, cross sop′teryg′ee-eye (G. *krossoi*, fringe; *pteron*, wing)........................425, 642

CROTALINE SNAKES (G. *krotalon*, a rattle) *733*

CROWN OF TOOTH *735*

CRURA CEREBRI, kroo′ra cĕ′rebri (L. *crus*, leg + *cerebrum*, brain) 572, 839, 860

CRUREUS, kroo′reus (L. *crus*, leg).. 82
  The vastus internus muscle of the thigh.

CRUS, krŭs (L. *crus*, leg) 45, 708

CRUSTACEA, krustā′shiâ (L. *crusta*, a crust) 421, 429
  A class of *Arthropoda*, mostly aquatic, that breathe by gills.

CRYPTOBRANCHUS ALLEGHENIENSIS, kriptobrang′kus (G. *kryptus*, hidden + *brangchos*, gill).........648

CRYPTOCEPHALA, kriptōsef′alâ (G. *kryptos*, hidden + *kephale*, head)..420
  An order of *Polychaeta*.

CRYPTODIRA, kriptodī′ra (G. *kryptos* + *deire*, neck) 652

CRYPTOGAMS, krĭp′tŏgăm (G. *kryptos*, hidden + *gamos*, union).......225

CRYPTONISCUS, krĭptonis′kus (G. *kryptos* + *oniskos*, a wood louse)..327

CRYPTURIFORMES, kriptū″ĭfor′mēz (G. *kryptos*, hidden + *oura*, tail + *forma*, form) 425
  Flying terrestrial birds with short tail and no pygostyle, as *Stinamus*.

CRYSTALLINE LENS, krĭs′tălĭn (G. *krystallinos*, crystalline) 70
  Transparent.

CRYSTALLOID, krĭs′tăloid (G. *krystallos* + *eidos*, form) 94

CTEIPHORA, tī′fŏră (G. *kteinein*, to kill + *pherein*, to bring)..........422
  A sub-class of *Arachnoidea*.

CTENOID, ten′oid (G. *ktein*, comb)..676

CTENOPHORA, tenŏf′ŏrâ (G. *ktenos*, a comb + *phoreo*, I bear).........427
  Transparent, free-swimming marine animals, the *Sea Walnuts* or *Comb Jellies*.

CUBITIS, kū′bĭtŭs (L. *cubitus*, elbow).*335*

CUBOID, kū′boid (G. *kuboeides*, cubelike) 109

CUBOMEDUSAE, ku'bōmēdū'sē (L. *cubus*, a cube + *medusae*, medusa). *256*, 419
  An order of *Scyphozoa*.
CUCULIFORMES, kū'kūlĭfôr'mēz (L. *cuculus*, a cuckoo + *forma*, form)..425
  Arboreal cuckoo-like birds with first and fourth toes directed backwards. The fourth toe may be reversible.
CULEX, ku'leks (L. *culex*, a gnat)...137
CULTURED MAN, definition of...... 27
CUNEIFORM, kiu'neeiform (L. *cuneus*, wedge) 709
CURSORIAL, kersō'rĭăl (L. *cursorius*, pertaining to running)............654
CUSP (L. *cuspis*, a point)......675, *736*
  A prominence, as on a tooth.
CUSPIDATUM, kus'pidātum (L. *cuspidatus*, made pointed)............*220*
  A species of *Sphagnum*.
CUTANEOUS, kiutay'neeus (L. *cutis*, skin) 793
CUTICLE, kū'tikl (L. *cutis*, skin).93, 267
  An outer skin or pellicle in zoology.
  The epidermis in botany.
CUTIS PLATES, definition of........591
CUVIER..........379, 384, 388, 386, 415
CUVIER, DUCT OF, definition of....501
CYCLOID, sigh'kloid (G. *kyklos*, circle), definition of *676*
CYCLOPS, sī'klops (G. *kyklops*, round-eyed) *305*
CYCLOPTERUS, sīklop'terus (G. *kyklos*, a circle + *pteron*, wing)...816
CYCLOSIS, sīklō'sis (G. *kyklosis*, a whirling round) 139
  The circulation or movement of protoplasm within a cell.
CYCLOSTOMATA, sigh'klostow'matah, (G. *kyklos*, circle; *stoma*, mouth)... ....424, 431, 640, 729
CYMOTHOIDAE, sīmōthō'idē (G. *kyma*, anything swollen + *thoos*, quick or pointed + *eidos*, resemblance) 327
CYNOHYAEDON, sīnohīē'don (G. *kynos*, dog + *hyaina*, hyena)......*734*
CYNTHIA BIPARTIA, sĭn'thia (G. *kynthos*, mountain in Greece)......*554*
CYPRINOIDS, sip'rĭnoids (G. *kyprinos*, a carp + *eidos*)..................761
CYPRIS, sī'pris (G. *kypris*, Venus)...*327*
CYST, sĭst (G. *kystis*, a bladder).....*151*
CYSTICERCUS, sĭs'tĭsĕr'kus (G. *kystis* + *kerkos*, tail)............294
  The larval form or bladder-worm stage of certain tapeworms.
CYSTOFLAGELLATA, sis'tōflajelā'ta (G. *kystis*, bladder + L. *flagellum*, whip) 151, 419
  An order of *Mastigophora*.
CYSTOGENOUS CELLS, sĭstŏj'ĕnŭs (G. *kystis* + *genos*, offspring).....*289*
  Large nucleated cells in the cercaria of distomum which secrete the cyst.
CYTOFACTS, sī'tofakts (G. *kytos*, hollow + L. *facere*, to make)...... 91
CYTOLOGY, sītŏl'ōjĭ (G. *kytos*, hollow + *logos*, discourse)........... 31
CYTOLYTIC, sītōlĭt'ĭc (G. *kytos* + *lysis*, loosing), definition of........200
CYTOPLASM, definition of.......... 90
CYTOSTOME, sī'tostōm (G. *kytos* + *stoma*, mouth) *150*
CYTOTROPIN, sī'tōtrō'pin (G. *kytos* + *trophe*, nourishment) 200

DACTYLOPOPODITE, dăk'tilŏp'odīt (G. *dactylos*, finger; *pous*, foot)...314
DACTYLOZOOID, dăk'tīlōzō'oid (G. *dactylos*, finger; *zoon*, animal).....255
DARBISHIRE, A. D. 164
DARWIN, CHARLES 262, 385, 388, 397, 403, 749
DARWIN, ERASMUS 384
DARWINIAN THEORY UNSATISFACTORY 397
DASYPUS SEXCINCTUS, dăs'ĭpŭs (G. *dasus*, hairy + *pous*, foot + L. *sex*, six, *cingo*, to bind around).........*659*
DAWSON 370
DECAPOD, dĕk'ăpŏd (G. *deka*, ten; *pous*, foot) 316
DECAPODA, dĕkăp'ōda 326
DECIDUA BASALIS, dēsid'ūā (L. *de*, away; *cadere*, to fall).........629
  Capsularis 629
  Reflexa 629
  Serotina 629
  Vera 629
DECIDUOUS TEETH, definition of..732
DEFERRED, definition of............178
DEGENERATION, dējĕnĕrā'shun (L. *degener*, base) 325
DE GRAAF 380
DELAMINATION, dēlăm'ināshun (L. *de*, down; *lamina*, a layer), definition of..................107, 557, 561
DELTOID, dell'toid (G. *delta*, fourth letter of the Greek alphabet, triangular in form) 80
DEMIBRANCH, dĕ'mĭbrank (G. *demi*, half + *branchia*, gill)............758
DEMOSPONGIAE, dēmōspon'jiē (G. *demos*, the people + *spongos*, sponge) 419, 427
  A class of porifera to which most sponges belong.

DENDRITES (G. *dendron*, tree)..... 68
DENDROCOELUM GRAFFI, dĕnd′rō-sē′lŭm (G. *dendron*, tree + *koilia*, bowels) *286*
Lacteum 285
DENSITY 37
DENTAL FORMULA, dĕn′tal (L. *dens*, tooth) 739
Ridge 732
DENTARY, den′taree (L. *dens*, tooth). *72*, 617, 697
DENTATUS GYRUS, dĕntā′tŭs jīrŭs (L. *dentatus*, toothed + *guros*, turn) *884*
Nucleus 859
DENTINE, den′tin (or teen), (L. *dens*, tooth), definition of..............732
DENTITION, dĕntish′un 732
DEPRESSOR MUSCLES, dēprĕs′or (L. *deprimere*, to lower).......78, 829
Nerve *755*
DERMAL BONES, dĕr′mal (G. *derma*, skin), definition of 677
DERMAL MUSCLES, definition of....826
DERMAPTERA, dermăp′terâ (G. *derma*, skin + *pteron*, wing).......426
An order of *Orthopteroidea*.
DERMARTICULARE, dĕr′mârtĭculā′-rē (G. *derma*, skin; L. *articulare*, to divide into joints)................697
DERMATOGEN, dĕr′mătōjen (G. *derma*, skin; *gignesthai*, to produce).*228*
DERMATOME, derr′matome (G. *derma*, skin; *tomos*, cutting), definition of 502
DERMIS, dĕr′mis (G. *derma*, skin)... 46
Component parts of 665
DERMOCHELYS CORLACEA, dĕr-mŏk′elĭs (G. *derma*, skin + *chelus*, tortoise) 652
DERMOPTERA, dĕrmop′tĕra (G. *derma*, skin + *pteron*, wing).......423
DERO, dē′rō (G. *dero*, neck).........286
A sub-class of *Oligochaeta*.
DEROTREMES, dērotrēms (G. *dero*, neck + *trema*, a hole).............760
DE SAUSSURE 381
DESCEMET'S MEMBRANE, definition of *579*
DESCRIPTION VS. EXPLANATION. 40
DESMOGNATHUS FUSCUS, dĕsmŏg′-năthus (G. *desmos*, a band, + G. *gnathos*, jaw) *648*
DESSICATION (L. *desiccare*, to dry up) 147
DEUTOMERITE, dūtŏm′ĕrīt (G. *deuteros*, second; *meros*, part)........*151*
DEUTOPLASM, dū′tōplasm (G. *deuteros*, second + *plasma*, something formed), definition of.............550
DEVELOPMENT, definition of....... 31
Of digestive canal *723*
DE VRIES, HUGO..........388, 403, 679
DEXTROSE (L. *dexter*, right + *glukos*, sweet) 187
DIAGNOSIS, dī′agnō′sis (G. *dia*, through; *gignoskein*, to know), correctness of 20
DIAPHRAGM, dye′aframm (G. *dia*, between; *phragnymi*, to inclose).*755*, 756
DIASTASE, dī′astās (G. *dia*, through; *histanai*, to set), definition of......268
DIASTOLE, dī′ăs′tōlē (G. *diastole*, difference) 58
DIATOM, dīatŏm (G. *dia*, through; *temnein*, to cut)..................124
DIBOTHRIOCEPHALUS LATUS, dībŏth′rēŏsĕf′ălŭs *296*, *301*
Same as *Bothriocephalus*.
DIBRANCHIA, dibrang′kiâ (G. *di*, two + *branchia*, gills)............421
An order of *Cephalopoda* with two gills, two kidneys, and two auricles. Shell enveloped by a mantle.
DICELLURA, dīsĕl′ūra (G. *dis* + *kulus*, hollow) 422
An order of *Campodeoidea*.
DICOTOPHYME RENALE (G. *dikotyledon* + *phyme*, to grow in the body) 306
DICOTYLEDON, dīkōtīlē′dŏn (G. *di*, two; *kotyledon*, cup-shaped hollow).*227*
DICYEMA PARADOXUM, dīsī′ēma (G. *dis*, twice + *kyema*, embryo)..*307*
DICYEMIDAE, disiem′idē (G. *di*, two + *kyema*, embryo) 306
DIDELPHIA, dīdĕl′fiâ (G. *di*, two + *delphis*, womb)..........426, 431, 657
Definition of 431
DIDELPHYS DORSIGERA, dīdĕl′fĭs dŏrsĭj′ĕrâ *657*
DIDINIUM, dī′dinium *139*
DIEMICTYLUS VIRIDESCENS, dīemĭk′tĭlos (G. *diameno*, to persevere + *ichthys*, fish)..............649
DIENCEPHALON, dīensef′alon (G. *dia*, between; *engkephalon*, brain)...... ....480, 840, *842*
DIFFERENTIATION, dif″eren′shiā-shun (L. *differe*, to differ).........
Anterior-posterior 265
Dorso-ventral 265
DIFFLUGIA, dĭfloo′jĭ′â (L. *diffluere*, to flow apart) *148*
A genus of *Rhizopods*.
DIFFUSION (L. *dis*, apart; *fundere*, to pour) 37, 38
Becoming widely spread.
DIGENEA, dījen′ēâ (G. *di*, two + *genes*, sexes) 420
Trematoda which pass through several different stages in their life history.

DIGENETIC, dījĕnĕt'ĭk (G. *dis*, twice; *gignesthai*, to produce)............288
DIGESTION, dījĕs'chun (L. *digestio*, digestion)......................30, 63
DIGESTIVE CANAL 47
  Glands 49
  System 47
  Tract, development of...........494
DIGIT, dij'ĭt (L. *digitus*, finger)..45, 708
DIGITATUM, dĭj'ĭtătŭm (L. *digitatus*, having fingers or toes) *256*
  Applied to leaves with finger-like divisions or processes.
DIGITIGRADE, dij'itigrade (L. *digitus*, finger, toe; *gradus*, step, walk).714
DILATOR, dīl'āt'or (L. *dilitare*, to expand) *763*
DIMORPHIC, dīmôr'fic (G. *dis*, twice; *morphe*, form) 255
DINOFLAGELLATA, dīnōflă'jēlātâ (G. *dinos*, a round area, + L. *flagellum*, a whip) 151, 419
  An order of *Mastigophora*.
DINORNITHIFORMES, dīnôrnithifôr'mēz (G. *deinos*, terrible, + *ornis*, bird + L. *forma*, form)...........425
  An order of extinct *Aves*, that were flightless, with enormous hind limbs, and no wing bones. The *Moas*.
DINOSAUR, dī'nôsawr (G. *deinos* + *sauros*, lizard) 651
DIOCOELE, dīo'sēl, opening in diencephalon, definition of 511
DIODON MACULATUS, dī'odon (G. *dis*, twice + *odous*, tooth).........*645*
DIOECIOUS, diē'shŭs (G. *dis*, twice + *oikia*, house) 217
DIOSCORIDES, dīōskor'ĭdēz (Name of Greek physician)..................376
DIPHYCERCAL, diff'eesir'kel (G. *diphyes*, twofold; *kerkos*, tail).....684
DIPHYODONT, dĭf'ēōdŏnt (G. *di*, two + *phein*, to produce + *odous*, tooth).733
  Having two sets of teeth.
DIPLOBLASTIC, dĭp'lōblăs'tic (G. *diploos*, double; *blastos*, bud); consisting of two germ-layers.........247
DIPLOCOCCI, dĭplōkŏk'sĭ (G. *diploos*, double + *kokkos*, berry)..........190
DIPLOGLOSSATA, diplōglōsā'ta (G. *diploos*, double + *glossa*, tongue)..423
  An order of *Orthopteroidea*.
DIPLOID, dip'loid (G. *diploos*, double + *eidos*), definition of............101
DIPLOPODA, diplop'ōdâ (G. *diploos*, double + *pous*, foot)..............422
  An order of *Progoneria*.
DIPNEUSTI, dipnūs'tĭ (G. *di*, two + *pneustos*; f. *pnein*, to breathe).425, 645
DIPNOAN, dĭp'nōan (G. *dis*, twice; *pnein*, to breathe)................684
DIPNOI, dip'noi (L. *dipnous*, double breathing) 425, 645
DIPTERA, dĭp'tĕrâ (G. *dis*, twice; *pteron*, wing)...........*330*, 345, 424
DIPYLIDIUM CANINUM, dīpēli'dium (G. *dipylos*, with two gates).......*296*
  Latum *301*
DISCOGLOSSUS, diskoglos'us (G. *diskos*, disk + *glossa*, tongue).....*813*
DISCOIDAL, SEGMENTATION, definition of 106
DISCOIDES, diskoi'des (G. *diskoeides*, disk-shaped) *148*
DISCOMEDUSAE, discōmēdū'sâ (G. *diskos*, a disk + L. *medusae*, medusa) 419
  An order of *Scyphozoa* in which umbrella is disk shaped.
DISCRIMINATION, definition of.....175
DISSECTION OF FROG............. *48*
DISSEPIMENTS, dĭsĕp'ĭments (L. *dis*, apart; *saepire*, to hedge in).......266
DISSIMILATION, definition of......125
DISTAL, dĭs'tal (L. *dis*, apart; *stare*, to stand), definition of.........76, 248
DISTENSIBLE 65
DISTILLATION 38
DISTOMA BUSKI (G. *dis*, two + *stoma*, mouth) 293
  A name for the various genera of *Trematoda*.
  Felineus *292*
  Sinensis 293
DISTOMUM CONJUNCTIVUM 292
DISTRIBUTION, dĭs'trĭbū'shun (L. *dis*, apart; *tribuere*, to allot), geographical, definition of 32
DIVERTICULA, dī'vĕrtĭk'ūlâ (L. *de*, away; *vertere*, to turn)............722
DIVISION OF LABOR, dĭvizh'ŭn (L. *dividere*, to divide), definition of..120
DOCILITY, definition of 175
DOG—
  Skull *694*
  Sweat-glands of.................674
DOGFISH—
  Brain *854*, *857*
  Dissected *753*, *802*
  Eye muscles of..................*827*
  Longitudinal section of..........853
  Urogenital organs *820*
DOG-SHARK 641
DOLICHOGLOSSUS KOWALEVSKI, dŏlĭkōglŏ'sŭs (G. *dolichos*, long + *glossa*, tongue) *546*
DOLPHIN *662*
DOMINANCE, definition of..........163
DORSAD, definition of. (See prefixes and suffixes at top of Index-Glossary,)
DORSAL AORTA, dôr'sal (L. *dorsum*, back) *48*

DORSO-VENTRALITY, definition of..265
DOUBLE CIRCULATION, definition of 535
DRACUNCULUS MEDINENSIS, drăkŭng'kūlŭs (L. little dragon)...*305*
  A genus of Nematode parasites.
DREPANIDOTAENIA SETIGERA...298
DRONE 353
DUALIST IN PHILOSOPHY........174
DU BOIS-REYMOND 380
DUCK-BILL *656*
DUCT OF BOTALLUS, dŭkt (L. *ducere*, to lead), definition of......531
  of gall bladder and pancreas.... *48*
DUCTLESS GLANDS 751
DUCTUS BOTALLI..............531, *596*
  Cuvieri 501
  Venosus 501
DUGUNG *661*
DUMAS 380
DUODENAL LOOP, definition of.....590
DUODENUM, diu'ohdee'num (L. *duodeni*, twelve) *48*, 49
DURA MATER, diu'rah mah'ter (L. *dura*, hard; *mater*, mother)....67, 838
DYAD, dīâd (G. *dyas*, two), definition of 102

EAR—
  External 869
  Inner 867
  Middle 869
  Of locust 336
  Stones 868
EAR BONES OF MAMMALS........*867*
EAR DRUM OF FROG.............. 45
EARTHWORM 262-284
  Behavior 281
  Circulatory system 269
  Digestive system 267
  Embryology 279
  Excretory system 272
  External appearance 264
  Grafting 283
  Internal structure 266
  Nervous system 273
  Oogenesis 279
  Regeneration 282
  Reproductive system 275
  Respiration 272
  Sense organs 275
ECDYSIS, ĕkdī'sis (G. *ek*, out; *dyein*, to enter), definition of 330
ECHIDNA ACULEATA, ekĭd'nă (L. *echidna*, an adder) *656*
  Hystrix *656*
ECHIDNIDAE, ekid'nidē (L. *echidna* + G. *eidos*) 657
ECHIDNODERMATA, ēkīnōder'mâtâ (G. *echinos*, a sea hedge-hog + *derma*, skin) 428
  Radially symmetrical, spiny-skinned sea animals.
ECHINOIDEA, ekinoi'dēâ (G. *echinos*, a hedge-hog + *eidos*, form)...420, 428
  A class of *Echinodermata* such as the sea urchin and sand dollar.
ECHINORHYNCHUS, ekīnōring'kus (G. *echinos* + *hynchos*, snout).....306
ECHIUROIDEA, ekiūroi'dēâ (G. *echis*, adder + *oura*, tail + *eidos*)........310
ECHIURUS PALLASI, ekiu'rus (G. *echis* + *oura*)....................*311*
ECOLOGY, ēkŏl'ōjī (G. *oikos*, house; *logos*, discourse).................. 31
  The study which deals with the relationship between organisms and their surroundings.
ECONOMIC BOTANY, definition of.. 32
  Zoology 32
ECTOBLAST, ĕk'tōblăst (G. *ektos*, without; *blastos*, bud)............
ECTOCHONDROSTOSIS, ĕk'tōkondrŏstō'sĭs (G. *ektos*, without; *chondros*, cartilage; *osteon*, bone), definition of 681
ECTODERM, ĕk'tōderm (G. *ektos*, outside; *derma*, skin), definition of....106
ECTOPLASM, ĕk'tōplazm (G. *ektos*, outside; *plasma*, something moulded). 310
  The external layer of protoplasm in a cell, usually slightly modified.
ECTOPROCTA, ĕktōprŏk'tâ (G. *ektos*, + *proktos*, *anus*), definition of.....310
ECTOSARC, ĕk'tōsark (G. *ektos*, outside; *sarx*, flesh), definition of.....121
EDENTATA, ee'dentay'tah (L. *e*, without; *dens*, tooth).............426, 658
EDUCATION 32
EDWARDSIIDEA, edwardzī'idē (named after Henry Milne-Edwards, a French naturalist). 420
  An order of *Zoantharia*.
EEL *644*
EFFERENT DUCTS, definition of....610
EFT *648*
EGESTION, ējĕs'chun (L. *ex*, out; *gerere*, to carry)................30, 63
EGG AXIS (Icel. *egg*), definition of..553
  Tooth, definition of..............737
EGGS, OF PARASITIC WORMS.....*301*
  Frogs *44*
EIMER 404
EJACULATORY DUCT IN EARTHWORM, ĕjăk'ūlătôry (L. *ex*, out; *jacere*, to throw)................272
ELASMOBRANCHII, eelas'mowbran'kee-eye (G. *elasmos*, plate; *branchia*, gills) 424, 641
ELASTIC SHEATHS, definition of...612

ELASTOIDIN, ēlastoĭ′din (G. *elastikos*, elastic) 699
ELECTROTROPISM, ēlektrōtrō′pizm (G. *electron*, amber + *trope*, turning), definition of 127
ELEMENTARY EMBRYOLOGY 100
ELEPHANTIASIS, elefantī′asis (G. for elephant disease) *304*
ELLIOT 592
ELYTRA, elīt′ra (G. *elytron*, sheath) .336
  The anterior wing of certain insects, hard and case-like; one of the scales or shield-like plates found on the dorsal surface of some worms.
EMBIDARIA 423
  A sub-class of *Siphunculata*.
EMBIIDINA 423
  An order of *Embidaria*.
EMBRYO, em′brĭō (G. *embryon*, embryo) 624
EMBRYOLOGICAL AREA, definition of 460
EMBRYOLOGY 31
  Elementary 100
  Of bee 362
  Of chick 433-543
  Of earthworm 279
  Of frog 543-618
  Of insects 346
  Of mammal 619-633
EMBRYONIC DISC OF CHICK *456*
  Of lizard *458*
EMBRYONIC SHIELD, definition of..624
  Sac *244*, 464
EMERIA STIEDAE *152*
EMOTIONS, definition of....174
EMPIS, em′pis (G. *empis*, a mosquito or gnat) *330*
EMULSION, definition of....50, 94
ENAMEL ORGAN, ĕnam′el (O. F. *esmaillier*, to coat with enamel), definition of 732
ENCYRTUS, enser′tus (G. *enkyrtos*, curved in) 345
ENCYST, ĕnsĭst′ (G. *en*, in; *kystis*, bladder) *127*, 129
  For a small animal or a cell to surround itself with an outer coat.
ENDOCARDIUM, ĕn″dōkâr′dĭŭm (G. *endon*, within; *kardia*, heart) 470
ENDOCRINE GLANDS, ĕndōkrīn (G. *endon*, within; *krinein*, to separate). 52
ENDOCRINOLOGY 744
ENDODERM or ENDODERMIS, ĕn′dōderm (G. *endon*, within; *derma*, skin), definition of....106, *229*, 230
ENDOLYMPHATIC DUCT, definition of 581, 867
ENDOLYMPH SAC, ĕndōlĭmf (G. *endon*, within; *lymph*, water) *866*
ENDOPARASITIC, ĕn′dōpăr′ăsīt′ĭk (G. *endon*, within; *para*, beside; *sitos*, food), definition of....288
ENDOPLASM, ĕn′dōplăzm (G. *endon*, within; *plasma*, something moulded)
  See Endosarc.
ENDOPODITE, ĕndŏp′ōdīt (G. *endon*, within; *pous*, foot) *314*
  The inner or mesial branch of a biramous crustacean limb, or the only part of a biramous limb remaining.
END ORGANS *864*
ENDORHACHIS, ĕndōr′ăkis (G. *endon*, within + *rachis*, spine) 838
ENDOSARC, ĕn′dōsârk (G. *endon*, within; *sarx*, flesh) 121
  The inner portion (or endoplasm) of the protoplasm in a cell.
ENDOSKELETON, ĕn′dōskel′etŏn (G. *endon*, within; *skelletos*, hard) 46
  The inner skeleton as opposed to the exoskeleton.
ENDOSPERM, ĕn′dōspĕrm (G. *endon*, within; *sperma*, seed), definition of 240, 245
ENDOSPORE, ĕn′dōspôr (G. *endon*, within; *sporos*, seed), definition of..191
ENDOSTYLE, en′dough′style (G. *endo*, within; *stylos*, column), definition of *544*, 744
ENDOTHELIUM, ĕn′dōthēl′ĭŭm (G. *endon*, within; *thele*, nipple), definition of 271, 470
ENERGY 30
ENGLISH LANGUAGE, need of.... 40
ENTAMOEBA BUCCALIS (G. *entos*, within + *amoeba*) 142
  Coli *144*
  Dentalis 142
  Gingivalis *142*
  Hystolytica 142
ENTEROBIUS VERMICULARIS *301*
ENTERON, ĕn′terŏn (G. *enteron*, gut) 280
  The alimentary tract.
ENTEROPNEUSTA 424, 640
ENTOCHONDROSTOSIS, ĕn′tōkŏndrostō′sis (G. *entos*, within; *chondros*, cartilage; *osteon*, bone), definition of 681
ENTODERM, en′toederm (G. *endo* + *derma*, skin) 106
ENTOMESODERM, definition of....362
ENTOMOLOGIST, ĕntōmŏl′ōjist (G. *entomon*, insect; *logos*, discourse), definition of 418
ENTONISCIDAE, entōnis′kidē (G. *entos*, within + *oniskos*, a wood louse) 327
ENTOPROCTA, entoprok′tâ (G. *entos* + *proktos*, anus), definition of....310

ENTOVARIAL CANAL, ĕn′tōvā′rĭăl (G. *entos*, within; L. *ovum*, egg), definition of 816

ENVELOPES, FLORAL, ĕn′vĕlŭps (F. *enveloppe*, covering) *242*

ENVIRONMENT, ĕnvī′rŏnmĕnt (F. *environ*, about) 32, 157

The sum total of the external influences acting on an organism.

ENZYME, ĕn′zīm (G. *en*, in; *zyme*, leaven) 95, 189

A chemical or unorganized, soluble ferment.

EPARTERIAL BRONCHI, ĕp′ârtērial bronkī (G. *epi*, upon; L. *arteria*, artery + G. *bronchus*, a windpipe) .770

The first branch of the right bronchus.

EPAXIAL MUSCLES, ĕpak′sĭăl (G. *epi*, upon; L. *axis*, axis), definition of 826

EPENDYMA, ĕpĕn′dĭmă (G. *ependyma*, outer garment), definition of......572

EPHEMEROIDEA 423

A sub-class of *Pterygogenea*.

EPIBLAST, ĕp′ĭblast (G. *epi*, upon; *blastos*, bud), definition of.........106

EPIBOLE or EPIBOLY, ĕpĭb′ōlĭ (G. *epi*, upon; *ballein*, to throw), definition of 107, 557

EPICARDIUM, ĕp′ĭkâr′dĭŭm (G. *epi*, upon; *kardia*, heart), definition of.520

EPICOELE, ĕp′ĭcēl (G. *epi*, upon; *koilos*, hollow), definition of........461

EPICORACOID, ĕp′ĭkôr′akoid (G. *epi*, upon; *korax*, crow; *eidos*, resemblance) 76

Pertaining to an element, usually cartilaginous, at the sternal end of the coracoid in amphibians, reptiles, and monotremes.

EPICRANIUM, ĕp′ĭkrānĭŭm (G. *epi*, upon; *kranion*, skull) 334

The region between and behind the eyes in an insect's head.

EPIDERMIS, ĕp′ĭdĕr′mis . (G. *epi*, upon; *derma*, skin) 46, 229

Component parts of.............665

EPIDIDYMIS, ĕp′ĭdĭd′ĭmĭs (G. *epi*, upon; *didymos*, testicle), definition of 284, 519, 814

EPIGENESIS, ĕp′ĭjĕn′esĭs (G. *epi*, upon; *gignesthai*, to be born), definition of 382

EPI-HYAL, ĕp′ĭhī′ăl (G. *epi*, upon; *hyoeides*, Y-shaped) 738

Pertaining to the upper portion of the ventral portion of the hyoid arch. As a noun, the upper element of the ventral portion.

EPIMERA, epi′mērâ (G. *epi* + *meros*, thigh), definition of 315

EPIMERE, ĕp′īmēr (G. *epi*, upon; *meros*, part) 460

EPIMYOCARDIUM, epĭ′mīō′kardium (G. *epi* + *mys*, muscle + kardia, .. heart), definition of 529

EPINEPHRIN, ĕpinĕf′rĭn (G. *epi* + *nephros*, kidney) 823

EPIPHARYNX, definition of 337

EPIPHYSIS, ĕpif′ĭsĭs (G. *epi*, upon; *phyein*, to grow)......66, 490, 681, 852

Of frog 45

EPIPLOIC FORAMEN, ĕp′iplō′ik fôrāmen (G. *epiploon*, the caul + L. *foramen*, an opening).............

The opening between the bursa omentalis and the large sac of the peritoneum; the foramen of Winslow.

EPIPODITE, ĕpĭp′ōdīt (G. *epi*, upon; *pous*, foot) *314*

A process arising from the basal joint of the crustacean limb and usually extending into the gill chamber.

EPISTERNUM, ĕp′istĕr′nŭm (G. *epi*, upon; *sternum*, breast bone)....... 76

EPISTROPHEUS, ĕp′ĭstrō′fĕŭs (G. *epistropheus*, turning) 684

The axis vertebra.

EPITHALAMUS, ĕp′ithal′amus (G. *epi*, upon; *thalamos*, chamber), definition of 852

EPITHELIOID BODIES, definition of.587

EPITHELIUM, ĕp′ithē′lĭum (G. *epi*, upon; *thele*, nipple); surface tissue.108

EPITRICHIUM, ep′itrĭk′ium (G. *epi*, upon; *thrix*, hair) 657

An outer layer of the epidermis in the foetus of many mammals, usually shed before birth.

EQUAL SEGMENTATION, ēkwal (L. *aequalis*, equal), definition of......106

EQUATORIAL PLANE, ē′kwătôr′ĭăl (L. *aequalis*, equal)............... 98

EQUIDAE, ek′widē (L. *equus* + G. *eidos*, like) 662

EQUILIBRIUM, ORGAN OF....323, 869

EQUISETALES, ekwisētā′lēz (L. *equus* + *seta* + *ales*)...................*223*

One of the fern allies.

EQUISETUM FUNSTONI, ekwisē′tum (L. *equus* + *seta*, bristle) *224*

One of the fern allies.

ERROR, PROBABILITY OF, CHART. 20

ERYOPS, er′iops (G. *eryein*, to draw out + *ops*, face)..................682

ERYTHROCYTES, ērĭth′rōsīts (G. *erythros*, red; *kytos*, hollow)....... 56

The red blood cells.

ESSENTIAL ORGANS, definition of..228

ETHICS 40

ETHMOID, ĕth′moid (G. *ethmos*, sieve; *eidos*, shape) ....

  Plate 540

  Where formed 615

ETIOGENOUS ....

EUGENICS, ūjĕn′iks (G. *eu*, well; *genos*, birth) 162

  The science dealing with the improvement of stock, usually referred to the betterment of the human race.

EUGLENA, ūglē′nă (G. *eu*, well; *glene*, pupil of the eye) 127

  A species of *Mastigophora*.

EULAMELLIBRANCHIA, ūlămelibrang′kia (L. *lamella*, a thin plate + G. *branchiae*, gills) 421

  An order of *Pelecypoda*.

EUSTACHIAN TUBE, ūsta′kĭăn (I. *Eustachi*, Italian physician), definition of 71, 499, 869

  Of frog 45

EUTHERIA, ūthē′riă (G. *eu*, well + *therion*, a beast) 426, 431, 657

  Definition of 431

EUTHYNEURA, ūthinū′râ (G. *euthys*, straight + *neuron*, nerve) 421

  A sub-class of *Gastropoda*.

EVAGINATION, ēvăjĭnā′shun (L. *e*, out; *vagina*, sheath) 294

  The process of unsheathing, or product of this process; an outgrowth.

EVAPORATION 38

EVIDENCE FOR EVOLUTION.......406

EVOLUTION, ĕvōlū′shŭn (L. *evolvere*, to unroll) 402-413

  Cause of 412

  Convergent 412

  Course of 412

  Criteria for a satisfactory theory of 413

  Divergent 412

  Evidence for 406

  Evidence against 408

  Individual 31

  Racial 31

  Summary of evidence............412

EXCRETION, ĕkskrē′shun (L. *ex*, out; *cernere*, to shift) 30

  Act of eliminating waste material, or the product of the process.

EXCRETORY SYSTEM............. 63

EXOCCIPITAL, eksoksip′ital (L. *ex* + *occiput*, back of head) 73

EXOCOELOM, ex′osē′lom (L. *ex* + G. *koilos*, hollow), definition of.......461

EXOCRINE GLANDS, eks′ŏkrīn (L. *ex* + G. *krino*, I separate) 52

EXONAUTES GILBERTI, eksōnâ′tēz (G. *exo*, outside + *nautes*, sailor) ..644

EXOPODITE, ĕksŏp′ōdīt (G. *exo*, without; *pous*, foot) 314

  The outer branch of a typical biramous crustacean limb.

EXOSKELETON, ĕk′sōskĕlĕton (G. *exo*, without; *skeletos*, hard) 347

  A hard supporting structure secreted by the ectoderm or by the skin.

EXPIRATION, ĕkspĭrā′shŭn (L. *ex*, out; *spirare*, to breathe) 30

EXTENSILE TONGUE 47

EXTENSION, definition of........43, 78

EXTENSORS 829

EXTERNAL CAPSULE OF BRAIN..849

  Gills 549

EXTERNAL EAR OF FROG, ĕkstĕr′nal (L. *externus*, outside) 45

EXTRA EMBRYONAL AREA, definition of 460

EXTRA EMBRYONIC MEMBRANES OF CHICK, ek′strâ-em′brĭon′ĭk (G. *exter*, outside; *embryon*, foetus)...463

EXTRINSIC MUSCLES, ĕkstrin′sik (L. *extrinsecus*, on the outside)....829

EXUMBRELLA, ĕksŭmbrĕl′a (L. *ex*, out; *umbra*, shade), definition of...254

EYE MUSCLES (M. E. *ighe*).......827

  Lens 491

  Birds 874

FABELLA, făbĕl′â (L. *fabbella*, a small bean) 710

FABRICIUS, făbrē′shus (L. *fabricus*, a German entomologist)...........381

FACIAL, fā′shal (L. *facies*, face)..... 68

FACIOLOPSIS BUSKI 292

FACTS, COORDINATING........... 40

FACTS VS. INTERPRETATIONS.... 32

FAECES, fē′sez (L. *faeces*, dregs).... 50

  The excrement or waste matter from the bowels.

FALCIFORM, făl′sifôrm (L. *falx*, sickle) 537

  Sickle-shaped or scythe-shaped.

  Process of eye.................876

FALCONIFORMES, făl′conifôrmēz (L. *falco*, a falcon + *forma*, form).....425

  An order of falcon-like *Aves* with curved beak, hooked at end, and sharp, strong claws.

FALLOPIAN, fălō′pĭan (after Fallopius, an anatomist). See Oviduct.

FALLOPIUS, ITALIAN ANATOMIST.378

FALX CEREBRI, fâlks cerebri (L. *falx*, a sickle)....................838

FAMILY, fămili (L. *familia*, the household) 415

FANNIA CANICULARIS 368

FASCIA, făsh'ia (L. *fascia*, a band or bandage) 78, 838
An ensheathening band of connective tissue.
FASCICULUS, FASCICULI, fa'sikulus uli (L. a little bundle) 828, 836
The direct pyramidal tract or tracts.
FASCIOLA HEPATICA, faseōla (L. a strip of cloth) *289*
The liver-fluke, also called *Distoma*.
FASCIOLARIS GYRUS, fas'ĭolā'rĭs jī'rus (L. *fasciola*, a small bandage).*844*
FASCIOPLOPSIS BUSKI 292, 301
FAT BODY (A. S. *faett*, fat)........ 48
FATS, definition of.................. 96
FAUCES, faw'sēs (L. throat).......739
FEATHER—
Development of 657
Structure of 670
Tracts 669
FEELINGS, definition of 174
FELIDAE 658
FELIS LEO *734*
FEMORAL, FEMORIS, fem'ōral, or is (L. *femur*, thigh) 792
Pertaining to the thigh.
FEMORAL PORES, definition of.669, 673
FEMUR, fē'mur (L. thigh), definition of 77, 707
FENESTRA OVALE 868
FENESTRA OVALIS................715
Rotunda 868
Tympani 868
FENUGREK ....
FERMENT, fĕr'mĕnt (L. *fermentum*, ferment)...................50, 92, 188
FERN ALLIES *224*
FERTILIZATION, fer"tilizā'shun (L. *fertilis*, fertile)................97, 104
Artificial 205
Meridian 550
FIBRILLAE, fībrĭl'ē (L. *fibrilla*, small fiber) 112
The thread-like branches of roots; minute elastic fibers secreted within spongin cells; minute muscle-like threads found in various *Infusoria*, (so called from being found in hay-infusions).
FIBROBLASTS 198
FIBROS SHEATH 617
FIBROVASCULAR BUNDLE 216
Bi-collateral 236
Closed collateral 236
Collateral 236
Complete 232
Concentric 236
Incomplete 232
Radial 236
FIBULA, fib'ūlă (L. clasp or buckle) 77, 703
The outer and smaller bone of the shin.
FICUS *234*
FIERASTER ACUS 644
FILAMENT, fil'ămĕnt (L. *filum*, thread) 75, 243
The stalk of the anther; the stalk of the down feather.
FILARIA BANCROFTI (L. *filum*, thread) *303*
Medinensis *305*
Oxardi *303*
FILARIIDAE 304
FILAR THEORY 95
FILIAL GENERATION, definition of.168
FILIBRANCHIA, filibrang'kia (L. *filum*, thread + *branchiae*, gills)...421
An order of *Pelecypoda*.
FILIFORM, fĭ'lĭfôrm (L. *filum*, thread + *forma*, form)..................739
Thread-like.
FILOPLUME, fil'ōplūm (L. *filum*, thread + *pluma*, feather).........670
A delicate, hair-like feather with long axis, and a few barbs at the apex.
FILUM TERMINALE 67, 837
FIMBRIA, fim'bria (L. fringe)......470
Any fringe-like structure.
FINLAY, DR. CHARLES...........136
FINS—
Undifferentiated *698*
FISCHER 191
FISHES—
Cranial nerves of...............*861*
Development of skull...........*539*
FISHING, FROG 645
FISSION, fish'ŭn (L. *fissus*, a cleft)..250
Cleavage of cells; division of a unicellular organism into two or more parts, thereby reproducing its kind.
FISSURE, fish'ūr (L. *fissus*, cleft)... 67
A cleft or deep groove, or furrow, dividing an organ into lobes.
Of brain 843
FISTULA, fis'tūla (L. *fistula*, a pipe, tube) 729
FIXED NERVE ARCS, definition of..180
FLAGELLATA, flajelā'ta (L. *flagellum*, whip).............143, 149, 418
An order of *Mastigophora*.
FLAGELLUM, flăjĕl'ŭm (L. a whip), definition of 127
FLAME CELLS, definition of.......286
FLATWORMS AND THREADWORMS 285-311
See Platyhelminthes and Nemathelminthes.
FLEAS *350*

FLEXION, flĕk′shŭn (L. *flexus*, bent) 43, 78
FLEXORS, definition of..........829
FLOCCULUS, flok′ūlŭs (L. a little piece of wool)..........859
  A small accessory lobe on each lateral lobe of the cerebellum.
FLORAL ENVELOPES, flō′ral (L. *flos*, flower) 242
  Organs 242
FLOUNDER 645
FLOWER (L. *flos*, flower), purpose of.242
FLOWERING PLANTS 203
FLOWERS (L. *flos*, flower)..........242
  The blossom of a plant, comprising generally sepals, stamens, and pistils.
  A leafy shoot adapted for reproductive purposes.
FLUKE, LIVER 289 293
  Asiatic lung 291
  Bronchial 291
FLY 367-371
  Foot of 333
  Head of 333
  Killers 371
  Life history 369
FLYING FISH 644
FOETUS, or FETUS, fē′tŭs (L. *foetus*, offspring) 624
  An embryo in the egg or in the uterus.
FOLIACEOUS, fōlĭā′shŭs (L. *folium*, a leaf) 315
  Leafy.
FOLIOSE LICHEN, fō′lĭōs lī′kĕn (L. *folium*, leaf; G. *leichen*, liver wort).
FOLLICLE, fŏl′ikl (L. *folliculus*, a little bag) 442
  A capsular fruit which opens on one side only.
FOLLICLE, GRAAFIAN 443
FONTANELLE, fŏntănĕl′ (F. a little fountain) 72, 684
  A gap or space between bones of the cranium, closed only by a membrane.
FOOT CELLS OF SERTOLI....520, 811
FORAMEN, FORAMINA, fôrāmĕn, rā′mĕnā ....
  Any opening.
FORAMENIFERA, fŏrămĭnĭf′ĕrâ (L. *foramen*, a hole; *ferre*, to bear).148, 418
  An order of *Rhizopoda*.
FORAMEN MAGNUM 72
  Of Panizza 786
  Ovale, definition of..........534
FORE BRAIN 472
  Gut 455-484
FOREIGN LANGUAGES, value of.... 41
FORMATION OF GERM LAYERS IN MAMMAL 622

FORMATIVE POLE, definition of....105
FORNICATUS GYRUS, fôrnĭkātŭs jirus (L. *fornicatus*, arched) 844
FORNIX, fôr′niks (L. an arch or vault) 845
  An arched sheet of longitudinal fibers beneath the corpus callosum.
FOSSA, fôs′ă (L. a pit or cavity).... 72
  A ditch or trench-like impression.
  Hypophyseos 687
  Rhomboidalis 860
FOSSIL, fôs′ĭl (L. *fossilis*, dug up)..
  Remains 399
  Index 398
FOSSORIAL 654
FOVEA CENTRALIS, fō′vēă (L. *fovea*, depression) 873
FRENULUM, frĕn′ūlŭm (L. a bridle or bit) ....
  A fold of membrane as of tongue or clitoris.
FRENUM, frē′nŭm (L. bridle).......739
  A frenulum.
FRICTION RIDGES 678
FROG—
  Arteries 59
  Brow spot 45
  Circulatory system 53
  Columella 45
  Digestive system 47
  Ear 45, 71
  Egg 44
  Embryology—
    Comparison of Tadpole and Chick.543
      Blastulation 553
      Classification of chordata......543
      Embryo formation 564
      Fertilization 550
      Gastrulation 556
      Later development of tadpole...569
      Lateral line organs..........582
      Maturation 552
      Medullary plate 562
      Nervous system 570
      Somites 568
    Digestive Tract 585
      Midgut derivatives 589
      Hindgut derivatives 590
    Mesodermal Somites 591
      Table of Somites..........592
    Circulatory System 594
      Arterial system 596
      Heart 594
      Origin of—
        Circulatory system 599
        Venous system 599
        Lymphatic system 602
      Septum transversum 604
    Urogenital System 605
      Adrenal bodies 610
      Epinephroi 610
      Mesonephros 608

Wolffian body 608
Skeletal system 612
Skull 613
Epiphysis 45
Eustachian tube 45
Excretory system 63
External features 44
Eye 69
Fat bodies 86
Glands 52
Heart 75
Histology ....10[illegible]
Internal structure 46
Iris 44
Medial eye 45
Muscular system 77
Names of 45
Nervous system 65
Olfactory organ 71
Orbit 44
Reproductive system 85
Respiration 62
Sense organs 68
Skeleton 73
Summary 117
Tongue 71
Touch and pressure.............. 71
Tympanic membrane 44
Veins 60
FROG-SPIT, definition of...........204
FROND, frŏnd (L. *frons*, leafy branch) *223*
A leaf, especially of fern.
FRONTAL, frun′tal (L. *frons*, brow) .. 73
In the region of the forehead.
FRONTALS 617
FRONTIGENA *335*
FRUIT, frūt (L. *fructus*, fruit), definition of 227, 242
FUCUS, fūkus, experiment on eggs of, (G. *fykos*, sea-weed) 206
FUNARIA, funā′riă (L. *funarius*, belonging to a rope)............*217, 220*
FUNCTIONAL PSYCHOLOGY, fŭngk′shunal (L. *functus*, performed), definition of 175
FUNDAMENTAL TISSUES, definition of 229
FUNDUS, fun′dus (L. the bottom; the base of an organ) ....
FUNGI, fŭn′jī (L. *fungus*, a mushroom)..................190, 203, 208
FUNGIFORM, fun′jiform (L. *fungus*, a mushroom) *739*
Shaped like a fungus.
FUNGI TUBE 208
FUNICULUS, fiunik′yulus (L. a small rope or cord)...............*244*, 836
A small cord or band of fibers, especially in the brain.
FURCULA, fur′kiulah (L. a little fork) *329*, 704
A forked process or structure, the merry-thought bone.
FUSCA, fŭs′ka (L. *fuscus*, dark, dusky) *249*

GADOW 652
GADUS MORRHUA, gā′dus mŏrūa (L. *gadus*, cod-fish) *644*
GALEN 376, 388
GALL 750
GALL-BLADDER, gôl (A. S. *gealla*, gall) *48*, 50
GALLERIA MELLONELLA 365
GALL-FLY *345*
GALLIFORMES, galifôr′mēz (L. *gallus*, a cock + *forma*, form).....425
An order of fowl-like birds with feet adapted for perching.
GALLS *192*
GALTON 384
GAMBUSA, gambu′să (Cu. *gambasina*, nothing) 138
GAMETE, gă′mēt (G. *gametes*, spouse) 85
GAMETOCYTE, gămē′tōsīt (G. *gametes* + *kytos*, hollow)................132
GAMETOGENESIS, gămētôjĕn′ēsīs (G. *gametes* + *genesis*, birth).........*100*
GAMETOPHYTE, gămē′tōfīt (G. *gametes* + *phyton*, plant).....215, 220
GANGLIA, găng′glia (G. *ganglion*, little tumor) 68
Brain 847
GANGLION CELLS, gan′gleeon (G. a tumor) 115
Gasserian *65*
GANOID, gan′oid (G. *ganos*, bright) .643
GARPIKE *643*
GASSERIAN GANGLION, gasee′rian (from a physician, Gasser) ..*65*, 513, 884
Same as semilunar ganglion.
GASTRIC, gas′trik (G. *gaster*, stomach) 317
Of birds 754
GASTRIC MILL, diagram of.........317
GASTROCNEMIUS, gas′troknee′meus (G. *gaster*, stomach; *kneme*, shank) *80*
GASTROCOEL, gas′trohseal (G. *gaster*, stomach; *koilos*, hollow)..........722
GASTRO-HEPATIC OMENTUM......537
GASTROPODA, găstrŏp′ŏdă (G. *gaster* + *pous*, foot)................421, 424
A class of *Mollusca* such as snails, slugs, etc.
GASTROVASCULAR CAVITY, găstrôvăskūlăr (G. *gaster* + L. *vasculum*, a small vessel), definition of.......247
GASTROZOOID, găs′trōzō′oid (G. *gaster* + *zoon*, animal)............*255*

GASTRULA, gas′trewlah (L. a little stomach) ....
  Of Amphibian *451*
  Of Amphioxus *451*
  Of Bird *450*, *451*
  Of Frog *555*
GASTRULAR CLEAVAGE, definition of 556
  Groove 556
GASTRULATION, definition of 106
  Of frog *558*
GAULE, ALICE 51
GAVIALIDAE GANGETICUS 653
GECKONES, gek′ōnez (Malay, *gekok*, imitator) 654
GEGENBAUR 380
GELATIN, jĕl′ătĭn (L. *gelare*, to congeal) 93
GEMMAE, jĕm′â (L. plu. of *gemma*, bud) *222*
GEMMATION, jĕmā′shŏn (L. *gemma*) .189
GENAE, jē′nē (L. plu. of *gena*, cheek) .334
GENE, jēn (G. *gene*, descent) 166
GENETICS, jĕnĕt′ĭks (G. *gignesthai*, to produce) 32, 165, 171
GENICULATE BODIES, jĕnĭk′ūlāt (L. *geniculum*, little knee) 852
GENIOHYOID, jinye′ohigh′oid (G. *geneion*, chin; *upsilon*, a Y-shaped letter of the Greek alphabet) 81
GENITAL PORE, jĕn′ĭtăl (L. *gigno*, to reproduce) 284
GENU, jee′new (L. knee) ....
GENUS, jē′nŭs (L. *genus*, race) 415
GEOGRAPHICAL DISTRIBUTION... 32
GEOLOGIC CHART 394-395
GEOMETRY, gēom′etri (G. *geometria*, geometry, land measuring) 39
GEOTROPISM, jēŏt′rōpĭzm (G. *ge*, earth + *trepein*, to turn) 127
GEPHYREA, jefirē′â (G. *gephura*, a mound) 310, 424, 432
  Worm-like animals of uncertain position.
GERM, jĕrm (L. *germen*, bud) 190
GERM-BAND OF INSECT *362*
  Layers 280
  Plasm 99
  Ring 556
  Wall 451
GERMINAL CELLS, jĕrm′ĭnăl (L. *germen*, bud) 572
  Disc 443
  Epithelium *442*
  Vesicle 443
GERMINATE 220, 224
GERMINATIVUM, jerr′minaytivum (L. *germino*, to sprout) 665
GERYONIA, jerĭō′nia (G. *Geryon*, Geryon, a three-bodied giant) 254
GERYONIIDAE, jer′ĭōnĭdē (G. *geryon*) *253*
  A family of *Coelenterates*.
GESNER 378
GESTATION, jĕstā′shŭn (L. *gerere*, to carry) 619
GIANT FIBERS, definition of 374
GIBBON *660*
GIGANTORHYNCHUS GIGAS... *305*, 306
GIGANTOSTRACA, gīgantos′trakâ (G. *gigos*, giant + *ostrakon*, a shell) ... 421
  An order of *Merostoma*.
GIGARTINA *205*
GILA MONSTER, Hēla 654
GILL-ARCH, gĭl (M. E. *gille*, gill), Theory of 699
  Clefts 498
  Pouches 498
  Septa 775
  Slits 729
GIRAFFIDAE, jĭraf′ĭdē (Ar. *zaraf*, giraffe + *eidos*) 660
GIZZARD, gĭz′ărd (M. E. *gizer*, gizzard) 267, 745
GLANDICEPS HACKSI *546*
GLANDS, glăndz (L. *glans*, an acorn) 52
  Acid *361*
  Acinous *673*
  Adrenal 53
  Alkaline *361*
  Anal 673
  Bowman's 872
  Buccal 742
  Calciferous 268
  Carotid *55*, *59*, 588, 743
  Cement *340*
  Cloacal 673
  Colleterial *340*
  Cowper's 820
  Digestive 49
  Ductless 751
  Endocrine 52
  Exocrine 52
  Green 321
  Harder's 875
  Intermaxillary 741
  Internasal 741
  Of internal secretion 751
  Labial 741
  Lachrymal 582
  Lymph *800*
  Mammary 673
  Meibomian 673
  Molar 742
  Mucous 46
  Necrobiotic 673
  Orbital 742
  Palatal 742
  Pineal 490
  Pituitary 490
  Poison *361*
  Prostate 819
  Prostate of *Hirudina* 282
  Pterygopodial 668
  Red *761*
  Retrolingual 742
  Salivary 741, 742

  Sebaceous 673
  Sebific 344
  Serous 742
  Spleen 604
  Stenson's 872
  Sub mandibular 742
  Sweat 672
  Sweat in amphibia 63
  Tarsal 673
  Thymus 53, 587, *743*
  Thyroid 53, *743*
  Tubular 49
  Uropygial 670
  Vitally secretory 673
  Vitelline *292*
  Wax 364
GLENOID, glee'noid (G. *glene*, a socket) 76
  Cavity *703*
GLIA CELLS, glī'ă, glē'ă (G. *glia*, glue) 572, 835
GLOBIGERINA, glōbĭj'ĕrī'na (L. *globus*, globe) 148
  An ooze largely composed of Foraminifera shells.

GLOMERULI OF NERVES..........881
GLOMERULUS, glowmer'yulus (L. *glomus*, a ball of yarn)............ *64*
GLOSSINA PALPALIS, glosī'na (G. *glossa*, tongue) 144
GLOSSOPHARYNGEAL, gloss'ohfarin'jeeal (or fār'injē'al), (G. *glossa*, tongue; *pharynx*, pharynx) .. 68
GLOTTIS, glott'iss (G. *glotta*, tongue) 48, 588
GLUTEUS, glūtee'us (G. *gloutos*, rump) 80
GLYCOGEN, glī'kōjĕn (G. *glykos*, sweet + *lyein*, to loosen)................ 51
GNATHOSTOMATA, nath'ohstow'matâ (G. *gnathos*, jaw; *stoma*, mouth) 424, 431, *641*, 729
  Definition of 431
GOBLET CELLS, gŏb'lĕt (L. *cupellus*, a little cup)...................49, *109*
GOEHLICH 277
GOETHE 384
GOLGI 134
  Apparatus 91
GONAD, gonn'ad (G. *gonos*, seed).... 85
GONANGIA, plu. of *gonangium*......252
GONANGIUM, gŏnăn'jĭūm (G. *gone*, seed + *anggeion*, vessel)..........253
GONIALE, gŏn'ĭālē, gōnĭālā (G. *gonia*, corner) 697
GONIONEMUS, gōnio'nēmus (G. *gonia*, an angle, corner).......*253*, 254
  A *Coelenterate.*

GONOTHECA, gŏn'ōthē'ka (G. *gone* + *theke*, cup) *252*
GONOTOMES, gŏn'ōtōmz (G. *gone* + *temnein*, to cut)....................519
GORDIIDAE, gôrdī'ĭdē (G. *gordios*, king of Phergia)....................308
GORDIUS AQUATICUS *308*
  Lineatus *308*
GORGONACEA, gorgon'ācēa (G. *gorgos*, grim, fierce)..............420
  An order of *Anthozoa.*
GORILLA ENGENA, gōril'ă (G. *gorilla*, native name of the wild creature) *660*
GOSSYPARIA MANNIFERS (L. *gossypion*, a cotton-tree)..............349
GRAAFIAN FOLLICLE, grahf'ean (after de Graaf, a Dutch physician). 440, *443*, *620*
GRACILIS, grăss'ĭlĭs (L. *slender*).82, *156*
GRAIN LOUSE 350
GRANULES, grăn'ūlz (L. *granulum*, small grain) 89
GRANULOMA COCCIDIOIDES.......212
GRANULOSUM 665
GRASSHOPPER 332
  Behavior 348
  Circulatory system 338
  Digestive system 337
  Excretory system 339
  External appearance 334
  Internal anatomy 337
  Muscular system 343
  Nervous system 340
  Paedogenesis 345
  Polyembryony 345
  Reproductive system 343
  Respiratory system 339
  Senses 341
GRASSI 132
GRAY 385
GRAY CRESCENT, definition of......552
  Matter of nervous system....67, 836
GREBES 417
GREEN FELT, definition of..........207
  Glands 321
GREEK, value of 39
GREGARINA 143, 153
GREGARINIDIA, grĕgărĭn'ĭdĭa (L. *gregarius*, gregarious)........152, 419
  An order of *Telosporidia.*
GROWTH 30
  Zone 556
GRUB 348
GRUIFORMES, grūĭfŏr'mēz (L. *grus*, a crane + *formia*, formed like)....425
  An order of crane-like birds such as cranes, rails, etc.
GRYLLOBLATTOIDEA (L. *gryllus*, a cricket + *blatta*, cockroach or moth) 423
  An order of *Orthopteroidea.*
GRYLLUS PENNSYLVANICUS *342*
  A cricket.

GUARD CELLS *236*

GUBERNACULUM, giu′bernak′yulum (L. a rudder) 818
GUDERNATSCH 52
GULEA 335
GULLET, gŭl′ēt (L. *gula*, gullet) 127
GYMNOPHIONA, jĭmnofī′ōna (G. *gymnos*, naked + *ophioneos*, serpent-like) 425, *504*, 647
GYNAECOPHOROUS CANAL, jĭnē′kō-fōrŭs (G. *gyne*, woman + *pherein*, to carry) *291*
GYNANDROMORPHS, jĭnăn′dromorfs (G. *gynandros*, of doubtful sex + *morphe*, form) 366
GYNOECIUM, jĭnē′sĭŭm (G. *gyne* + *oikos*, house) *203*
  Same as pistil.
GYRUS, jī′rus (plural, *gyri*), (G. *gyros*, round) 843

HABENULA, haben′yula (L. a little band) 856, 571
HABITS, definition of 180
HAECKEL, ERNST 385
HAECKEL'S LAW OF BIOGENESIS .407
  Invalidity of 161, 409
HAEMAL ARCH, hēm′al arch (G. *haima*, blood) 681
HAEMATOBIA SERRATA, hēmatō′bĭa (G. *haima* + *bios*) 369
HAEMATOCHROME, hĕm′ătōkrōm (G. *haima*, blood + *chromos*, color) .128
HAEMATOCOCCUS *185*
HAEMATOZOIN, hĕm′ătōzō′ĭn (G. *haima* + *zoon*) 132
HAEMATUM (G. *haimatos*, of blood) .709
HAEMOCYANIN, hēm′ōsī′ănĭn (G. *haima* + *kyanos*, dark blue substance) 318
HAEMOGLOBIN, hēm′ōglō′bĭn (G *haima* + *globos*, sphere) 56, 269
HAEMOLYTIC, hēmōlĭ′tĭk (G. *haima* + *lyein*, to dissolve) 200
HAEMOSPORIDIA, hēmo′spōrĭd′ia (G. *haima* + *spora*, seed) 143, 153, 419
HAG FISHES, definition of 641
HALE 380
HALF-BREEDS 166
HALICORE DUGUNG, hălĭk′ōre, doogung (G. *hals*, sea + *kore*, made) .*661*
HALL 380
HALLER 380
HALLERI CAMPANULA 876
HALLUX, hăl′luks (G. *hallux*, toe) 77, 710
HALMATURUS, halmatū′rus (G. *halma*, spring + *oura*, tail) *672*
HALZOUN, hal′zūn 292
  A disease caused by the liver fluke.
HANDLIRSCH 418
HAPLOID, hăp′loid (G. *haploos*, simple + *eidos*, like) 101
HAPLOMI 643
HARDER'S GLAND 875
HARE-LIP, definition of 500
HARVEST MITES *350*
HARVEY..........378, 386, 388
HAVERSIAN (*Havers*, English physician) *110*
HEAD KIDNEY 504
HEART—
  Beat, when it begins..........522
  Development of *477*
  Development of, in chick........468
  Of frog *55*, 57
  Synangium *55*
  Ventricle *55*
HEATING 38
HEAT-REGULATING APPARATUS.. 38
HEGNER, R. W. 418
HEIDELBERG JAW *399*
HELIOZOA, hē′liōzō′a (G. *helios*, sun + *zoon*) *148*, 418
  An order of *Rhizopoda*.
HELLBENDER *648*
HELMHOLTZ 380
HELODERMA HORRIDUM 654
HEMIARCYRIA 205
HEMIAZYGOUS VEIN, hemĭaz′ĭgos (G.*hemi*, half + *azygos*, unyoked) .797
HEMICHORDATA, hĕm′ĭkŏrdā′tâ (L. *hemi*, half; *chorda*, cord) 424, 431, 640
HEMIDACTYLUS TURICUS, hĕmĭdăk′tĭlŭs (G. *hemi* + *daktylos*, a finger) *655*
HEMIPTERA, hĕmĭp′tĕră (G. *hemi* + *pteron*, wing) 424
  An order of *Rhynchota*.
HEMISPHERES OF BRAIN..........843
HEMISUS GUTTATUM *701*
HENBANE, hĕn′bān (A. S. *hennebell*, lit. hen-bell) *234*
HENLE'S LOOP, definition of...505, 806
HENSEN, LINE OF, definition of....114
HENSEN'S NODE, definition of.....453
HEPAR, hē′pâr (L. *hepar*, liver).....
HEPATIC (L. *hepar*, liver) *234*
HEPATICA (L. *hepar*, liver) *234*
HEPATIC PORTAL SYSTEM........ *50*
HEPATOLYTIC, hēp′ătō′lĭtĭk (L. *hepar* + *lycin*) 200
HEPTANCHUS, heptang′kus (G. *hepta*, seven + *angchein*, to choke) .766
HERBIVEROUS, herbiv′orus (L. *herba*, grass + *vorare*, eat) 660
HEREDITY, hĕrĕd′ĭtĭ (L. *hereditas*, heirship) 32
HERMAPHRODITE, hermaff′rowdite (G. *Hermes*, mercury; *Aphrodite*, *Venus*) ....
  Frog *822*
  Moth *366*
  True, definition of 822

HERRICK 851, 854

HESPERONITHIFORMES, hesperonĭtheform'ez (G. *esperos*, west + *ornis*, bird + form)....................425

An order of fossil, toothed birds with teeth in a groove.

HESSIAN FLY *354*

HETEROCOELA, het'erohsee'lah (G. *heteros*, different; *koilos*, hollow)..419

HETEROCERCAL, hĕt'ĕrōsĕr'kăl (G. *heteros* + *kerkos*, tail)...........685

HETEROCYEMIDAE 306

HETERODONT, het'erohdahnt (G. *heteros*, different; *odon*, tooth).....733

HETEROGENESIS, hĕt'ĕrōjĕn'ĕsĭs (C. *hetero* + *genesis*) 403

HETEROMETABOLOUS, hĕt'ĕrōmĕtăb'olŭs (G. *heteros* + *metabole*, change) 331

HETEROMI 643

HETEROMORPHOSIS, hĕt'erōmôr'fōsĭs (G. *heteros* + *morphe*, shape)..282

HETEROPHYES *292*

HETEROTRICHA, hĕtĕrŏt'rīkâ (G. *hetros*, other + *thrix*, hair)..154, 419

An order of *Ciliata*.

HETEROTROPHIC, hĕt'ĕrōtrŏf'ĭk (G. *heteros* + *trephein*, to nourish)....186

HETEROTROPIC CHROMOSOME, definition of 168

HETEROZYGOUS, hĕtĕrōzī'gŭs (G. *hetero* + *zygein*, to yoke).........167

HEXACTINELLIDA, hĕksăktĭnel'idâ (G. *hex*, six + *actis*, ray)....419, 427

An order of *Porifera*, such as the deep sea-sponges.

HEXANCHUS, heksang'kus (G. *hex* + *agchein*, to choke)................766

HEXAPODA, hĕksăp'ōdâ (G. *hex*, six + *pous*, foot).....................328

HIND BRAIN 66, 472

Gut 486

HIPPOCAMPUS, hip'pohkam'pus (G. *hippos*, horse; *kampos*, sea-monster)

Barbouri *644*

Of brain 843

HIPPOCRATES 376

HIRUDINEA, hĭrūdin'ēâ (G. *hirudo*, leech)..................283, 421, 428

A class of *Annelida* without setae or parapodia, but with suckers.

HIRUDO MEDICINALIS, hirū'do (L. *hirudo*, leech) *282*

HISTOLOGY, hĭstŏl'ōjĭ (G. *histos*, tissue + *logos*, discourse)......... 31

Of frog 108

Plant 228

HISTORIA ANIMALIUM 378

HISTORY OF BIOLOGY.........375-392

HODGE 370

HOFER 124

HOLDFAST 187

HOLOBLASTIC, hŏl'ōblăs'tĭk (G. *holos*, whole; *blastos*, germ).......279

HOLOCEPHALI, holosef'alē (G. *holos* + *kephale*, head).............424, 642

HOLOMETABOLOUS, hŏl'ōmĕtăb'ōlŭs (G. *holos* + *metabole*, change).....331

HOLOPHYTIC, hŏlōfĭt'ĭc (G. *holos* + *phyton*, plant) 128

HOLOSTEI, holoss'tee'eye (G. *holos*, whole; *osteon*, bone)..........425, 643

HOLOTHURIA, holothu'ria (G. *holothourion*, a kind of zoophyte)......*644*

HOLOTHUROIDEA, hŏlōthūroi'dea (G. *holos*, whole + *thourios*, rushing) 420, 428

A class of *Echinodermata* with ovoid, muscular body-wall and tentacles around mouth. Example: sea-cucumbers.

HOLOTRICHA, hŏlŏt'rĭkâ (G. *holos*, whole + *thrix*, hair)..........153, 419

An order of *Ciliata*.

HOLOZOIC, hŏl'ōzō'ĭk (G. *holos* + *zoon*, animal) 129

HOMOCERCAL, hŏm'ōsĕr'kăl (G. *homos*, the same; *kerkos*, tail).....685

HOMOCOELA, hōmōsē'lâ (G. *homos*, same + *koilos*, hollow)...........419

An order of *Porifera*.

HOMODONT, hŏm'ōdŏnt (G. *homos* + *odous*, tooth) 733

HOMOGENEOUS, homojē'nēus (G. *homos* + *je'nos*, race or family)...111

HOMOLOGIES 119

Serial 316

HOMOLOGUE, hŏm'ōlŏg (G. *homos* + *logos*, speech) 65

HOMOPTERA, hŏmŏp'tĕrâ (G. *homos* + *pteron*, wing)..................424

An order of *Rhynchota*.

HOMOZYGOTE, hŏm'ōzī'gōt (G. *homos* + *zygein*, to yoke)...............167

HOMOZYGOUS, hŏmo'zigus (G. *homos* + *zygein*, to yoke)...............167

HONEY-COMB OF STOMACH.......745

HOOKE, ROBERT 378

HOOKER 385

HOOKWORM EGGS *301*

HORMONE, hôr'mōn (G. *hormao*, to excite) 52, 823

HORSE-HAIR SNAKES 308

HORSETAILS *224*

HORTUS SANITATIS, hor'tus sanita'tis (L. *hortus*, garden + *sanitas*, health) 377

HOSTS OF TAPEWORMS...........297

HOW TO STUDY.................. 27

HUMERUS, hiu'merus (L. the bone of the upper arm)................76, 708

HUMUS, hū'mŭs (L. *humus*, earth)..263

HUNTER, JOHN 380

HUXLEY, THOMAS........365, 380, 385

HYAENA CROCUTA (G. *hyaina*, a hyena) *734*
HYALINE, hī′ălĭn (G. *hyalos*, glass) .111
HYALOPLASM, hī′ălōplăsm (G. *hyalos* + *plasma*, something moulded) 90
HYDATINA, hīdăt′ĭnâ (G. *hydatis*, watery vesicle) *308*
HYDRA FUSCA, hī′dra fus′ka (G. *hydra*, water snake; *fuscus*, dark brown) 247
HYDRANTH, hī′drănth (G. *hydor*, water + *anthos*, flower) 252
HYDRAZOA, hī′drăzō′ă (G. *hydor* + *zoon*) 256, 419, 427
  A class of *Coelenterata*.
HYDROCAULI, hī′drō′kôlī (G. *hydor* + *kaulos*, stalk) 252
HYDROCORALLINAE, hīdrōkoralī′nē (G. *hydra*, water + L. *corallinus*, *coralline*) 419
  An order of colonial *Hydrozoa*.
HYDROFUGE PLATES, hī′drofūg (G. *hydor* + L. *fugare*, to put to flight) .137
HYDROMETERS, hīdrom′eter (G. *hydrometrion*, a vessel for measuring hydrostically) 38
HYDROPHYLLIUM, hīdrōfĭl′ĭŭm (G. *hydor* + *phyllon*, leaf) 255
HYDROPHYLLUM, hī′drofĭl′um (G. *hydor* + *phyllon*, a leaf) *242*
HYDRORHIZA, hī′drōrī′ză (G. *hydor* + *rhiza*, root) 252
HYDROTHECA, hī′drōthē′kă (G. *hydor* + *theke*, cup) 252
HYGROMETERS, hīgrom′eter (G. *hygros* + *metron*, a measure) 38
HYGROSCOPIC, hī′grōskŏp′ĭk (G. *hygros*, wet + *skopein*, to regard), definition of 217
HYLOBATES ENTELLOIDES, hīlob′ătēz (G. *hylobates*, one who haunts the woods) *660*
HYMENIUM, hīmē′nēūm (G. *hymen*, skin) *207*
HYMENOCHIRUS 650
HYMENOLEPIS DIMINUTA, hīmĕnol′ĕpĭs 298, *301*
  Nana (G. *nanus*, dwarf) 298
HYMENOPTERA, hī′mēnŏp′tĕră (G. *hymen* + *pteron*, wing) *345*, 423
  A sub-class of *Siphunculata*.
HYOBRANCHIAL APPARATUS, hīōbrăng′kĭăl (G. *Y* + *brangchia*, gills) 617
  Support 738
HYOGLOSSUS, hī′ōglŏs′ŭs (G. *Y* + *glossa*, tongue) 81
HYOID ARCH, hī′oid (G. *hyoeides*, Y shaped) 73
HYOSTYLIC, hī′ōstĭlĭk (G. *Y* + *stylos*, pillar) 698
HYPARTERIAL BRONCHI, hĭp′ârtē′rĭăl (G. *hypo*, under + L. *arteria*, channel) 770
HYPAXIAL MUSCLES, hĭpax′eeal (G. *hypo*, below; *axis*, axis) 826
HYPERMASYISM, definition of......675
HYPERTHELISM, definition of......675
HYPERTROPHY, hīpĕr′trōfī (G. *hyper*, above + *trophe*, nourishment) 679
HYPHAE, hīfē (G. *hyphe*, web) 208
HYPHOMYCETES, hī′fōmīsē′tēz (G. *hyphe*, web + *mukus*, fungus) 210
HYPOBLAST, hī′pōblăst (G. *hypo* + *blastos*, bud) 106, *565*
HYPOBRANCHIAL PLATE, hī′pōbrăng′kĭăl (G. *hypo* + *brangchia*, gills) 617
HYPOCHORDAL ROD, hī′pōkôrdăl (G. *hypo* + *chorde*, string) 590
HYPOCOELE, hī′pōsēl (G. *hypo* + *koilos*, hollow) 459
HYPOCONID, hīpōkō′nĭd (G. *hypo* + *konos*, cone) 736
HYPOCOTYL, hīpôkŏt′ēl (G. *hypo* + *kotyle*, hollow) 239
HYPODERMIS, hī′pōdĕr′mĭs (G. *hypo* + *derma*, skin), definition of.......229
HYPOGASTRIC, hīpōgăs′trĭk (G. *hypo* + *gaster*, belly) ....
HYPOGLOSSAL, high′pohgloss′al (G. *hypo*; *glossa*, tongue) ....
HYPO-ISCHIUM, hī′pōĭs′kĭŭm (G. *hypo* + *ischion*, hip) 706
HYPOMERE, high′poh′mere (G. *hypo*, below; *meros*, part) 460
HYPONOMEUTA 345
HYPOPHARYNX, hīpōfăr′ĭngks (G. *hypo* + *pharynx*, gullet) 337
HYPOPHYSIS, hīpŏf′ōsēz (G. *hypo*, below; *phyo*, to cause to grow) .66, 490
HYPOSTOME, hī′pōstōm (G. *hypo* + *stoma*, mouth) 253
HYPOTHALAMUS, hī′pōthăl′ămŭs (G. *hypo* + *thalamos*, chamber) ...839, 851
HYPOTRICHA, hī′pŏt′rĭka (G. *hypo* + *thrix*, hair) 154, 419
  An order of *Ciliata*.
HYRACOIDEA, hīrăkoi′dēa (G. *hyrax*, shrew-mouse + *eidos*, like) 426, 662
HYRAX ABYSSINICUS *662*

IATRO-CHEMICAL SCHOOLS, īātrokem′ikal (G. iatros, a *physician* +... E. chemical) 380
  Mechanical schools 380
ICHNEUMON FLY, iknū′mon (G. *ichneumon*, the tracker)..............*372*
ICHTHYOPHIS GLUTINOSA *647*

ICHTHYOPSIDA, ik′thyop′sidah (G. *ichthys*, fish; *opsis*, appearance), definition of 663
ICHTHYOPTERYGIA, ĭk′thĭŏptērĭj′ĭă (G. *ichthys*, fish + *pteryx*, wing), definition of 707
ICHTHYORNITHIFORMES (G. *ichthys*, fish + *ornis*, bird) 425
An order of fossil, toothed-birds with teeth in separate sockets.
ICHTHYOSAURS, ik′thiosârs (L. *ichthyosaurus*, fish-like lizards)....699
IGNEOUS FORMATIONS, ig′nēŭs (L. *ignis*, fire), definition of...........393
IGUANA TUBERCULATA, igwa′na (Sp. *iguana*, from native Carib name) *655*
ILEUM, ill′eum (G. *eilo*, twist)....*48*, *49*
Definition of 338, 748
ILIACUS, ilī′akŭs (L. *iliacus*, relating to the colic) 80
ILIO-COSTALIS MUSCLE, ĭll′ĭō-kŏs′tălis (G. *eilo* + L. *costa*, rib)......829
ILIOPSOAS, iliop′sōas (L. *ilium*, the flank + G. *psoa*, a muscle of the loins), definition of 83
ILIUM, ill′eeum (L. flank).......... *76*
Homologue 704
IMAGE, im′ăje, APPOSITION, (L. *imago*, image), definition of.........322
Mosaic. definition of..............321
Stipple, definition of 321
Superposition. definition of.......322
IMAGO, ĭmā′gŏ (L. *imago*, image)...331
Definition of 348
IMMUNITY, imū′nitĭ (L. *immunis*, exempt from public service)...194, 201
Active 197
Artificial 197
Familial 196
Individual 196
Natural 197
Passive 197
IMPERFECT FLOWER. definition of.228
IMPLANTATION, implanta′shŭn (L. *in* + *plantare*, to plant)..........624
IMPORTANCE VS. CONSPICUOUSNESS 32, 375
IMPREGNATION, ĭm′prĕgnā′shŭn (L. *impraegnare*, to fertilize), definition of 105
(See also fecundation, fertilization, etc.)
IMPULSE, im′pŭls (L. *impulsus*, impelled) 178
INCISOR, insī′sor (L. *incido*, cut into) *703*
Teeth *734*
INCISURES OF SCHMIDT, definition of 114
INCOME, LOSS OF BY INSECTS....332
INCOMPLETE FIBRO-VASCULAR BUNDLES, definition of...........232
INCREASE IN FLIES...............370
INCUS, inn′kuss (L. anvil)..........*867*
INDENTATION, indentā′shun (L. *indentare*, to indent), definition of...106
INDEX FINGER, in′dex (L. *indicare*, to indicate), definition of..........710
Fossils 398
INDUSIUM, ĭndū′zĭŭm (L. *induere*, to put on) 225, 242
INFECTIONS, BY CESTODES, infek′shun (L. *inficere*, to infect)........295
By nematodes....................302
Mixed 196
Trematode 291
INFECTIVE TREMATODES *292*
INFRAORBITAL LINE. ĭn′frăôr′bĭtăl (L. *infra*, below + *orbis*, circle)...582
INFUNDIBULUM, inn′fundib′yulum (L. funnel) *65*
(See also hypophysis, pituitary body.)
Definition of 66, 852
Of oviduct *440*
INFUSORIA, ĭn′fūzō′rĭă (L. *infusus*, poured into + *forma*, shape)..419, 427
definition of 153
Why so named 138
INGEN-HOUSZ 381
INGESTED (L. *ingestus*, taken in).. 63
INGESTION (L. *ingestus*, taken in).. 30
INGLUVIES, ĭngloov′ĭēz (L. *ingluvies*, crop) 338, 744
INHERITANCE, inher′ităns (L. *in* + *heres*, heir) 157
INHIBITION, ĭn′hĭbĭsh′ŏn (L. *inhibere*, to prohibit) 52
INHIBITORY FIBERS, definition of..847
INITIATIVE, inish′iātiv (L. *initiare*, to begin), definition of...........175
INNER CELL MASS, ĭn′ĕr (A. S. *inra*, inside), definition of 621
INNER EAR—
Of frog 45
INNER STIMULUS. definition of....178
INNERVATION, ĭn′nĕrvā′shŭn (L. *in*, into + *nervus*, sinew)..........46, 77
INNOMINATE, inn′nomm′inate (L. *innominatus*, without a name)......
Artery 755
INNOVATION BRANCHES, ĭn′ôvā′shun (L. *innovare*, to renew)......220
INORGANIC, inôrgan′ik (F. *inorganique*, inorganic) 95
INSECTA, ĭnsĕk′tâ (L. *insectus*, cut off).....................328-374, 429
Bee 353
Fly 367
Grasshopper 332
Alternation of generations in.....346
Central nervous system of...*330*, *359*
Embryology of 346, 362

  Excretory system 359
  Gynandromorphs 366
  Metamorphosis 362
  Muscular system 360
  Paedogenesis 345
  Parasitic forms 372
  Polyembryony 345
  Senses of 341
  Sympathetic nervous system....359
  Vermin *350*
INSECTIVORA, ĭn'sēktĭv'ôră (L. *insectus* + *vorare*, to devour)...426, 658
INSERTION, OF MUSCLES, īnser'shŭn (L. *insertus*, joined) 78
INSPIRATION, ĭnspīrā'shŭn (L. *inspirare*, to inhale) 30
INSTARS, ĭn'starz (L. *instar*, form).330
INSTINCT, in'stingt (L. *instinctus*, impulse) 126
INSTINCTS, definition of 177
INSTRUCTION, instruk'shon (L. *instruere*, to build) 32
INSULA, in'sula (L. *insula*, island)..843
INTEGUMENT, integ'ument (L. *intego*, to cover), component parts of 665
INTELLIGENCE, intel'ijens (L. *intelligentia*, discernment), definition of.182
INTERACTIONIST, definition of.....175
INTERAURICULAR SEPTUM, ĭn'tĕrôrĭk'ūlăr (L. *inter*, between + *auricula*, little ear + *septum*, partition) 541
INTERBRANCHIAL SEPTUM, ĭn'tĕrbrang'kĭăl (L. *inter* + G. *branchia*, gills) 758
INTERCOSTAL ARTERIES, ĭn'tĕrkŏs'tal (L. *inter* + *costa*, rib) 791
INTERMAXILLARY GLANDS (L. *maxilla*, jaw) 741
INTERMEDIATE CELL MASS (L. *medius*, middle) 593
INTERMEDIATE MASS OF BRAIN, definition of 863
INTERMEDIATE ORGANISMS..185, 193
  Bacteria 190
  Yeasts 188
INTERMEDIUM 76
INTERNAL CAPSULE OF BRAIN, definition of 849
INTERNAL GILLS 586
INTERNAL SECRETIONS 52
INTERNAL SECRETIONS, glands of. 52
INTERNAL STRUCTURE 46
INTERNASAL GLANDS (L. *nasus*, nose) 741
  Plate, definition of 613
INTERNODE (L. *nodus*, knot) *203*
INTERORBITAL SEPTUM (L. *orbis*, circle), definition of 540
INTEROSSEOUS (L. *os*, bone) 85
INTERPRETATIONS VS. FACTS.... 32
  Of facts 157
INTERRENAL (L. *renes*, kidneys), definition of 822
INTERRENAL VEINS 798
INTERSEGMENTAL 602
INTERSTITIAL, stĭsh'ăl (L. *sistere*, to set) 248
INTERSTITIAL CELL 819
INTESTINAL LAYERS 49
INTESTINE, CROSS SECTION OF, intes'tĭn (L. *intestinus*, inside).... *49*
INTRALIMBRICUS 844
INTRINSIC MUSCLES, ĭntrĭn'sĭk (L. *intrinsecus*, inwards) 829
INTROSPECTIONISTS, intrōspek'shonists (L. *introspectare*, to look into), definition of 173
INTUSSUSCEPTION, ĭn'tŭssŭsēp'shŭn (L. *intus*, within + *suscipere*, to receive).
  In Zoology, growth from within outwards; in Medicine, one portion of the intestine being pushed into another portion.
INVAGINATE, ĭnvăj'ĭnĕt (L. *in*, into + *vagina*, sheath) 259
INVAGINATION, innvaj'inay'shun (L. *in*, in; *vagina*, sheath), definition of.106
INVENTORS VS. SCIENTISTS 25
INVERSION, OF GERM LAYERS, inver'shon (L. *invertere*, to turn about) *623*
INVERTEBRATES, ĭnvĕr'tĕbrāts (L. *in*, not + *vertebra*, joint) ....
  Of uncertain position 431
INVOLUTION, ĭn'vŏlū'shun (L. *involvere*, to roll up) 557
IRIS, eye'riss (G. rainbow), definition of 70
  Of eye 873
IRRITABILITY, ĭr'ĭtăbĭl'ĭtĭ (L. *irritare*, to provoke) 65
ISCHIADIC ARTERY, ĭs'kĭăd'ĭk (G. *ischion*, hip) 792
ISCHIOPODITE, ĭs'kĭŏp'ôdīt (G. *ischion* + *pous*, foot) *314*
ISCHIUM, is'kēum (G. *ischion*, hip)..*76*
  Homologue 704
ISHNOPSYLLUS *350*
ISLE, ISLET, OR ISLAND OF REIL.843
ISOETALES, fern allies, īsoetā'lez (G. *isoetes*, equal in years) *224*
ISOPOD, ī'sōpŏd (G. *isos*, equal + *pous*) 316
ISOPODA, definition of 326
ISOPTERA, īsôp'tĕră (G. *isos* + *pteron*, wing) 423
ISTHMUS, OF BRAIN, ĭs'mŏs (G. *isthmos*, neck), definition of 845
  Of oviduct *440*
  Of pharynx 759
  Rhombencephali 839

IVORY, of tooth, ī'vôrĭ (L. *ebur*, ivory, f. French) 732

JACOBSON'S COMMISSURE, definition of 885
JACOBSON'S ORGAN, definition of 582, 870
  A diverticulum of olfactory organ of many vertebrates, often developing into an epithelium-lined sac opening into the mouth.
JEJUNUM, jee'jew'num (L. hungry), definition of 748
JUGAL, jew'gal (L. *jugum*, yoke), Malar bone 697
JUGULAR, jew'giular (L. *jugulum*, the collar bone) ....
JUNG 381

KALA-AZAR, kā'lāāzar (Hind. *kala*, black + *āzār*, sickness) 144
KAMMERER 649
KARYOPLASM, kăr'ĭôplāzm (G. *karyon*, nucleus + *plasma*, something moulded), definition of 90
KATABOLISM, kătăb'ôlĭzm (G. *kata*, down + *ballein*, throw), definition of 125
KATALYSTS 96
KATYDID *342*
KELLICOTT 592
KELLOGG, VERNON 179
KERATIN, kĕr'ătin (G. *keras*, horn) . 93
  The basis of epidermal structures, as horn, nails, hoof, etc.
KERATOSA, kĕr'atōs'a (G. *keras*) .. 419
  An order of *Porifera* with main skeleton of spongin.
  The regular bath-sponge, *Euspongia*.
KIDNEY, kĭd'nĭ (M. E. *kidnere*, kidney) 47, *48*
  Section of *817*
KING, A. F. A. 134
KINGSLEY 687, 806
KOCH, ROBERT 389
KOELLIKER, VON 389
KORSCHINSKY 403
KRAUSE, END-BULB OF *864*
KRAUSE'S MEMBRANE, definition of 114

LABIAL GLANDS, lay'beeal (L. *labium*, lip) 741
LABIATAE *366*
LABIUM, definition of 334
LABRUM, lā'brŭm (L. *labium*) ....
LABYRINTH, lăb'ĭrĭnth (L. *labyrinthus*, labyrinth) 749
  Membranes 868
  Nasal 871
  Of ear *866*

LACAZE-DUTHIERS 380
LACERTAE, lăsĕr'tā (L. *lacerta*, lizard), definition of 654
LACERTILIA, lăs'ĕrtĭl'ĭâ (L. *lacerta*, lizard) 425, 653
LACHRYMAL GLANDS, lăk'rēmal (L. *lacrima*, tear) 582
LACINIA, lăsĭn'ĭă (L. *lacinia*, flap), definition of 335
LACTEALS, lak'tēălz (L. *lac*, milk) *49*, 800
LACUNAE, lăkū'nā (L. *lacuna*, cavity), definition of 57, 111, 467
LAGENA, lajee'nah (G. *lagynos*, flask), definition of 867
LAMARCK 384, 386, 388, 397, 415
LAMBLIA, definition of 146
LAMELLAE, laimell'ee (L. *lamina*, a thin sheet), definition of 112, 320
LAMINA, lamm'eenah (L. a thin plate) 466, 856
LAMINA TERMINALIS, definition of. 570
LANCELET, definition of 639
LARVA, lâr'vă (L. *larva*, ghost) 43, 331, 547
LARVACEA 424, 639
LARYNGEAL CHAMBER, lărĭn'jēăl (G. *larynx*), definition of 588
LARYNX, lar'inks (G. *larynx*, gullet) 62, 74
  Definition of 728
LATEBRA, lăt'ĕbră (L. *latebra*, hiding-place) *438*
LATERAD ....
LATERAL, lăt'ĕrăl (L. *latus*, side) .. 269
  Folds 485
  Limiting sulci 485
  Line organs 853, *855*
  Nuclei 851
  Plate 461
  Ventricles 511
LATEX TUBES, lăt'ĕks (L. *latex*, fluid), definition of 235
LATISSIMUS DORSI, latiss'imus dor'si (L. the broadest) 79, 829
LATREILLE, PIERRE 415
LATTER 262, 276, 321
LAVERAN 134
LAVOISIER 390
LAW OF CONTINUITY 376
LAYERS OF INTESTINAL TRACT .. *49*
LEAF AXIL *203*
  Seed *203*
LEARNING, definition of 179
LEATHER, definition of 667
LEATHERBACK TURTLE 652
LEISHMANIA DONOVANI .. *144*
  Infantum *144*
  Jovanani *144*
  Tropica *144*
LEMNISCI, lĕmnĭs'kĭ (G. *lemniscus*, fillet) 851

LENS OF EYE, lĕnz (L. *lens*, lentil) .491
LENTICEL, lĕn′tisĕl (L. *lens*) *236*
LENTIFORM NUCLEUS, lĕn′tĭfôrm (L. *lens* + *forma*, shape) 849
LEPIDOPTERA, lĕp′ĭdop′tĕră (G. *lepis*, scale + *pteron*, wing) 423
An order of *Panorpoidea*.
LEPIDOSIREN *646*
LEPIDOSTEUS OSSEUS, lepp′idoss′-teeus (G. *lepis*, scale; *osteon*, bone) .*643*
LEPISMATOIDEA 422
An order of *Thysanura*.
LEPTODISCUS 151
LEPTOMEDUSAE, lep′tomēdū′se (G. *leptos*, thin + L. *medusa*) 419
An order of *Hydrozoa*.
LEPTOSTRACA 421
LEPTUS IRRITANS, lĕp′tŭs (G. *leptos*, small) *350*
LESION 209
LEUKOCYTE, lū′kôsīt, loo (G. *leukos*, white + *kytos*, hollow) 49, 57
LEUKOPLAST, lūkôplăst, loo (G. *leukos* + *plastos*, formed), definition of 237
LEVATOR, levay′tor (L. a lifter), definition of 78, 829
LEVERS, TYPES OF *36*
LEYDIG'S DUCT, definition of......809
LIBELLULOIDEA 423
A sub-class of *Pterygogenea*.
LICE *350*
LICHEN, lī′kĕn (G. *leichen*, liverwort) *205*
LIEBIG 380
LIEN, lē′ĕn (L. *lien*, spleen).
LIFE CYCLE 132
Of Angiosperm *244*
Of Hookworm 303
Of Liver-fluke 289
Of Plasmodium malariea.........131
Of Pine *241*
Of Tapeworm 293
Of Trichinae 302
LIFE HISTORY OF SPHAGNUM...221
LIGAMENT, lĭg′ămĕnt (L. ligamentum, bandage) 74
LIGNIN, lĭg′nēn, lĭg′nĭn (L. *lignum*, wood) 93
LIGULA, lĭg′ūlă (L. *ligula*, little tongue) 335
LIMITING SULCUS, definition of....845
LIMNACA *289*
LINEA ALBA, lĭn′ĕa ăl′bă (L. *linea*, line + *alba*, white) 79, 827
LINGUATULIDA, ling′gwatū′lĭdâ (L. *lingua*, tongue) 422, 430
A class of *Arthropoda*.
LINGULA, lĭng′gulă (L. *lingula*, little tongue) 310
LINNAEUS.................386, 388, *414*
LINNE, CARL VON (same as Linnaeus) ....
LININ, lī′nĭn (L. *linum*, flax) 90
Achromatic network of cell-nucleus.
LIPOCTENA 422
A sub-class of *Arachnoidea*.
LIPOIDS 95
LIRIOPE EXIGUA *253*
A coelenterate.
LISSAMPHIBIA, lĭs′ămfĭb′ĭâ (G. *lissos*, smooth; *amphibios*, double life) 425, 647
LISTER 36
LIVER, lĭv′ôr (A. S. *lifer*, liver)......*48*
Development of 589
Lobes of 47
LIZARDS 651
Pineal eye of *46*
LOA LOA *303*
LOBOSA, lō′bōs′ă (G. *lobos*, lobe).147, 418
An order of *Rhizopoda*.
LOBUS VAGI *844*
LOCALIZATION OF BRAIN CENTERS (L. *locus*, place)............854
LOCUSTIDAE 351
LOCY, WM. 385
LOEB, JAQUES 206
LOEMANCTUS LONGPIPES.........*701*
LOGIC (G. *logos*, discourse, word)... 40
LONGATA *205*
A species of spirogyra.
LONG-HORNED GRASSHOPPER....*352*
LONGISSIMUS CAPITIS, lonjiss′eemus cap′itis (L. the longest of the head) 829
Dorsi 829
LOPHIUS PISCATORIUS *645*
LOPHODONT, lŏ′fôdŏnt (G. *lophos*, crest + *odous*, tooth).............734
Having transverse ridges on the cheek-teeth grinding surface.
LOPHOPHORE, lŏ′fôfōr (G. *lophos* + *pherein*, to carry). An oval tentacle-supporting organ in Polyzoa and Brachiopods 309
LOW, DR. 136
LOXOPHYLLUM, ROSTRATUM *154*
LUCIDUM, loo′sĭdŭm (L. *lucidum*, clear) 665
LUDWIG 380
LUMBRICUS, lŭm′brĭkŭs (L. *lumbricus*, earth-worm) *259*
Herculeus *270*
Terrestris *268*
LUMPY-JAW, definition of..........213
LUNATUM, lūnā′tŭm (L. *luna*, moon).709

LUNG, lŭng (A. S. *lunge*, lung) *48*
  Alveoli *63*
  Development of 588
  Fishes 645
  Fluke 291
LYCOPODIALES *224*
  One of the Fern Allies.
LYCOPODIUM *224*
  A Fern Ally.
LYELL 384
LYMPH, limmf' (L. *lympha*, clear water) 62
  Duct 780
  Gland *800*
  Heart *54*, *57*
  Vessels 57, *800*
LYMPHOCYTES, lĭm'fōsīts (L. *lympha* + G. *kytos*, hollow), definition of .. 800

MACACUS, makā'kus (Sp. *macaco*, word of African origin), definition of *678*
McGREGOR, J. H. 400
McINDOO 342
MACHAIRODUS CULTRIDENS 734
MACHILOIDEA 422
  An order of *Thysanura*.
MACROCLEMMYS TEMMINCKI *719*
MACRODRILI 421
  An order of *Oligochaeta*.
MACROGAMETES, măkrôgă'mēts (G. *makros*, large + *gametes*, spouse), definition of 130
MACROMERES, măk'rômērs (G. *makros* + *meros*, part) 279
MACULA LUTEA, măk'ūlă (L. *macula*, spot + *luteum*, yellow), definition of 873
MADREPORARIA, măd'rēpōrā'rīâ (L. *mater*, mother + G. *poros*, a light friable stone) *257*, 420
  An order of *Zoantharia*.
MADURA DISEASE, definition of 214
MADURELLA MYCETOMA *214*
MAGELLANIA FLAVESCENS *311*
MAGENDIE 380
MAGGOTS, măg'ŏtz (M. E. *magot*, a grub). The most lowly organized, completely worm-like insect larva without insect appendages or distinct head 370
MAILED FISHES, definition of 676
MAJOR GROUPS OF ANIMALS, may'jor (L. the greater) 426
MALACOBDELLA GROSSA *307*
MALACOPTERYGII 643
MALACOSTRACA, măl'ăkŏs'trăkă (G. *malakos*, soft + *ostrakon*, shell) 316, 421
  Definition of 326
MALAR, may'lar (L. *mala*, cheek) ... 697
MALARIA, definition of 134
MALARIAE, PLASMODIUM, definition of 130
MALE TO FEMALE, development of in *Cymothoidae* 327
MALLEUS, mahl'eeus (L. hammer) 716, *867*
MALLOPHAGE, mălŏf'âgâ (G. *mallos*, a lock of wool + *phagein*, eat) 423
  An order of *Blattaeformia*.
MALPIGHI, mălpig'ē .. 379, 382, 386, 388
MALPIGHIAN, mălpig'ēan (after Malpighi, an Italian biologist).
  Body or corpuscle *64*
  Layer 665
MAMMAL, mam'mal (L. *mamma*, breast) ....
  Cranial nerves of *881*
  Skull of *694*
MAMMALIA, mamay'leeah (L. *mamma*, breast) 426, 431
  Definition of 656
MAMMALIAN EMBRYOLOGY .. 619-633
  Allantois 628
  Attachment of blastodermic vesicle 623
  Blastoderm 621
  Decidual membranes 620
  Embryonic membranes 625
  Fertilization 620
  Formation of germ-layers 622
  Implantation 624
  Placenta 626
  Umbilical cord 631
  Yolk-sac 627
MAMMARY GLANDS, mam'aree (L. *mamma*, breast), definition of 673
MAMMILLARY BODIES OF BRAIN, definition of 852
MAMMOTH *398*
MANATEE *661*
MANATUS *661*
MANDIBLE, MANDIBULAR, man'dibl, mandib'yular (L. *mandibula*, jaw) *661*
MANDIBULAR ARCH, definition of .. 74
MANNA, măn'ă (G. *manna*, manna), definition of 349
  The hardened exudation of the bark of certain trees (bot.); honeydew secreted by certain Coccidae (zool.)
MANSON, SIR PATRICK 135
MANTOIDEA 423
  An order of *Blattaeformia*.
MANUBRIAL CARTILAGE, mănū'br'ăl (L. *manubrium*, handle) 617
MANUBRIUM, maniu'breeum (L. handle) *251*
MANUS, may'nuss (L. hand), definition of *708*
  Of frog 45
MANYPLIES, definition of 745

MARCHAL 345
MARCHIAFAVA 134
MARINE 654
MARROW, definition of 112
MARSH 380
MARSUPIALIA, marsu'pēā'liā (L. *marsupium*, a pouch) 426
  Definition of 657
MARSUPIUM, definition of....................619
MASSA INTERMEDIA 863
MASSETER, masee'ter (G. *maseter*, a chew) 81
MASTIGAMOEBA, mas'tigamē'ba (G. *mastix*, a whip + *amoibe*, change), definition of 149
MASTIGOPHORA, mastĭgŏf'ōrâ (G. *mastix*, a whip + *phoros*, to bear) 127, 143, 149, 418, 427
MASTOID, măs'toid (G. *mastos*, breast) ....
  The name of the protruding bone directly behind the ear.
MATERIALIST, definition of 175
MATHEMATICAL SCIENCES 39
MATRIX, mā'triks (L. *mater*, mother)
  The ground substance of tissues....110
MATTER AND MIND 174
MATURATION, măt'ūrā'shŭn (L. *maturus*, ripe), definition of.......100
MAXILLA, maxill'ă (L. *maxilla*, the jaw bone) 48, 73
MAXILLAE, maxill'ā 313
MAXILLIPEDS, maxĭl'ĭpēdz (L. *maxilla* + *pes*, foot)....................313
  An appendage in Arthropods posterior to the Maxillae.
MEANDRINA *257*
MEATUS, meā'tus (L. passage), definition of 869
MEATUS VENOSUS, definition of....501
MECHANICAL TISSUES, definition of 234
MECHANICS 37
MECKEL 380
MECKEL'S CARTILAGE, definition of.616
  Diverticulum, definition of.......628
MEDIA, mē'diā (L. *medius*, middle)..*335*
MEDIAL EYE 45, 66
MEDIASTINUM, mē'dĭăs'tĭnŭm, ăstīnŭm (L. *mediastinum*, servant)....*755*
MEDULLA OBLONGATA, mĕdŭl'a ŏb'-long'gātă (L. *medulla*, marrow, pith + *oblongatus*, oblong).........*66*, 839
  Definition of 845
MEDULLARY, medd'ulayree (L. *medulla*, marrow, pith)....................812
MEDULLARY CORDS, definition of..520
MEDULLARY FOLDS, definition of..460
  Groove, definition of 460
  Plate, definition of 460
  Rays, definition of 231, 235
  Sheath, definition of 114
MEDULLATED NERVE FIBERS, definition of 836
MEDUSA, mĕdū'sā (G. *medousa*, one who rules) *251*
  A jelly-fish.
MEGALOPS ATLANTICUS, mĕg'ălŏps (G. *megalon*, great + *ops*, eye).....*644*
  Larval stage of certain crustaceans, conspicuous by large stalked eyes. Habitat—Atlantic ocean.
MEGALOPTERA, megalŏp'tera (G. *megas*, great + *pteron*, wing.......423
  An order of *Neuropteroidea*.
MEGASPORANGIA, mĕgăspôrăn'ji'ă (G. *megas*, large; *sporos*, seed; *anggeion*, vessel) 238
MEGASPORE CONES, definition of..238
MEGASPOROPHYLS, mĕg'ăspō'rôfĭlz (G. *megas* + *sporos* + *phyllon*, leaf), definition of 238
MEIBOMIAN GLANDS, mībō'mĭăn, definition of 673
MEISSNER'S CORPUSCLE *864*
  Plexus, a gangliated plexus of nerve fibers in the submucous coat of the small intestine....................*879*
MELANDER 418
MELANIN, mĕl'ănĭn (G. *melas*, black), definition of 132
MELANOPLUS DIFFERENTIALIS..*335*
  Femur-rubrum *352*
MEMBRANOCRANIUM, definition of.687
MENDEL....................162, 384, 388
MENDELIAN THEORY 163
MENTAL, men'tal (L. *mentum*, chin).616
MENTAL PHENOMENA 173
MENTO-MECKELIAN, mĕn'tômĕkē'lĭăn (L. *mentum*, chin + Meckel).. *72*
  A cartilage bone present in a few lower vertebrates at either side of the union of the two halves of the lower jaw.
MENTUM, definition of.............335
MERIDIAN, FERTILIZATION, definition of 550
MERIDOGASTRES 422
  An order of *Lipoctena*.
MERISTEM, definition of............228
MEROPODITE, mērŏp'ôdīt' (G. *meros*, thigh + *pous*, foot) *314*
MEROSTOMATA, mĕrŏstŏm'mătâ (G. *meros*, thigh + *stoma*, mouth).421, 429
  A class of *Arthropoda*.
MEROZOITES, mĕrōzo'īts (G. *meros* + *zoon*) 152
  Definition of 132

MESENCEPHALON, měs′ĕnsĕf′ălŏn, (G. *mesos*, middle + *en*, in + *kephale*, head) 472
MESENCHYME, mess′enkime (G. *mesos*, middle; *enchyma*, in a fluid).247
Definition of 259
Formation of 461
MESENTERIC, mess′entare′ik (G. *mesos*, middle; *enteron*, gut) 532
MESENTERIES, definition of........537
MESENTERIES IN *HYDRA*—
Definition of 256
MESENTERON 320
MESENTERY, mĕs′entarey (G. *mesos*, middle; *enteron*, gut) 47, *49*
MESOBLASTIC BANDS, mĕsôblăs′tĭk (G. *mesos* + *blastos*, bud), definition of 279
MESOCARDIA, definition of.....529, 604
MESOCARDIUM, mĕs′ôkâr′diŭm (G. *mesos* + *kardia*, heart), definition of 470, 776
MESOCOELE, mĕs′osēl (G. *mesos* + *koilos*, hollow), definition of.......511
MESOCOLON, mĕs′oko′lōn (G. *mesos* + *kolon*, large intestine), definition of 537
MESODERM, mess′ohderm (G. *mesos*, middle; *derma*, skin), definition of. 107, 724
Origin of in chick...............456
MESOGASTER, mess′ohgas′ter (G. *mesos*, middle; *gaster*, stomach), definition of 537
MESOGASTRIUM, definition of......745
MESOGLEA, mĕs′oglē′ă (G. *mesos* + *gloia*, glue), definition of..........247
MESOGONIMUS HETEROPHYES....293
MESOHEPATICUM (G. *mesos* + L. *hepar*, liver), definition of..........604
MESOMERE, mess′ohmere (G. *mesos*, middle; *meros*, part), definition of.. ....460, 503, 504
MESONEPHROS (G. *mesos* + *nephros*, kidney), development of...........503
MESORCHIUM, messor′keeum (G. *mesos*, middle + *orchis*, testis), definition of 609, 811
MESOSTERNUM, mĕs′ōstĕr′nŭm (G. *mesos* + L. *sternum*, breast bone)..335
MESOTHORAX, mĕs′othō′răks (G. *mesos* + *thorax*, chest)............614
The middle segment of the thoracic region of insects.
MESOTIC CARTILAGE 609
MESOVARIA, definition of......*440*, 811
MESOVARIUM, messohvay′reeum (G. *mesos*, middle; L. *ovum*, egg)..424, 431
MESOZOA (G. *mesos* + *zoe*, life)....306
Three families of parasites of uncertain position.
MESOZOIC, mĕs′ozō′ĭk (G. *mesos* + *zoe*) 394
The middle or secondary group of rock-systems.
METABOLISM, mĕtăb′olĭzm (G. *metabole*, change) 95
METACARPAL, met′akar′pal (G. *meta*,.. after; *karpos*, wrist).............. 76
METACARPUS, definition of.........708
METACONE, mĕt′ăkōn (G. *meta*, after + *konos*, cone) *736*
The posterio-external cusp of an upper molar.
METACONID, mĕt′ăkō′nĭd (G. *meta* + *konos* + *cidos*, resembling)........254
The posterio-internal cusp of a lower molar.
METAGENESIS, definition of........254
METAGONIMUS YOKOGAWAI *301*
METAMERE, met′amere (G. *meta*, after; *meros*, part), definition of... ....264, 460
METAMORPHOSIS, mĕt′ămôr′fôsĭs (G. *meta*, beyond + *morphe*, form), definition of 330, 504
Of bee 362
Of frog 547
METAPHASE, mĕt′ăfāz (G. *meta* + *phainein*, to appear).............. *97*
Definition of 98
METAPLASM (G. *meta* + *plasm*, something moulded), definition of.. 91
METAPODIUM, mĕt′ăpō′dĭŭm (G. *meta* + *pous*, foot), definition of...708
METATARSUS, mĕt′ătâr′sŭs (G. *meta* + L. *tarsus*, ankle), definition of...708
METATHALAMUS, mĕt′ăthăl′ămŭs (G. *meta* + *thalamos*, chamber), definition of 852
METATHERIA, mĕtâthē′rĭa (G. *meta*, beyond + *therion*, a wild beast)....431
Definition of 657
METATHORAX (G. *meta* + *thorax*, chest) 335
Posterior segment of the thorax of insects.
METATROPHIC, mĕt′ătrŏf′ĭk (G. *meta* + *trophe*, nourishment)......191
Definition of 258
METAZOA, mĕtâzō′â (G. *meta* + *zoon*)
Many-celled animals. Definition of. 96
METRATERM, mē′traterm (G. *metra*, uterus + L. *terminus*, end)........*296*
METRIORHYNCHUS *682*
MIASTORCA, mīas′torka (G. *miastor*, a guilty wretch, also avenger).....*345*
MICROCENTRUM RETINERVE *352*
MICRODRILI 421
An order of *Oligochaeta*.

- *MICROFILARIA*—
  - *Diurna* *303*
  - *Nocturna* *303*
- MICROGAMETES, mī′krôgă′mētz (G. *mikros*, small + *gametes*, spouse) .. 130
- MICROMERES, mī′krômērs (G. *mikros*, + *meros*, part) 279
  - A cell of the upper pole in meroblastic eggs.
- MICRON, mī′kron (G. *mikros*, small). One thousandth part of a millimeter. 190
  - Definition of *239*
- MICROPYLE, mī′krôpīl (G. *mikros* + *pyle*, gate), definition of 105
- MICROSPORES (pollen) 243
- MICROSPOROPHYTES (G. *mikros* + *sporos*, seed + *phyta*, plant), definition of 238
- MICROTOME 39
- *MICRURA* LEIDY *307*
- MID-BRAIN 66
  - Definition of 472
- MIDGUT, definition of 486
- MIGRATIONS, mīgrā′shŭnz (L. *migrare*, to transfer), of plants and animals 396
- MIGRATORY CELLS, ameboid cells of the blood 247
- *MIGULA* 190
- MILK DENTITION, definition of 732
- MILNE-EDWARDS 380
- MINCHIN'S CLASSIFICATION 151
- MIND, definition of 174
- MIND AND MATTER 174
- MINIMUS, mĭn′ĭmŭs (L. *minimus*, least). The fifth digit, definition of. 710
- MIRACIDIA, mĭr′āsĭd′ĭă (G. dim. of *meirakion*, a stripling), definition of *289*
- *MIRIENTOMATA* 422, 430
- MITE, ITCH *350*
- MITOCHONDRIA, mĭtokŏn′drĭă (G. *mitos*, thread + *chondros*, grain), definition of 91
- MITOSIS, mĭtō′sĭs (G. *mitos*, a thread), definition of 97
  - Meaning of 99
- MITRAL VALVE, mī′tral (F. *mitre*, a peaked cap), definition of 786
- MIXED NERVES, definition of 576
- MIXIPTERYGIUM, mĭk′sĭptĕrĭj′ĭŭm (G. *mixis*, mixing + *pterygion*, little wing) 707
- MODERN LANGUAGES 41
- MOLAR GLAND, mō′lar (L. *mola*, millstone) 742
- MOLAR TEETH, mō′lăr (L. *molere*, to grind) 734
- MOLDS, in paleontology, definition of. 398
- MOLE *658*
- *MOLLUSCA*, mŏlus′kă (L. *molluscus*, soft) 259, 429
  - Unsegmented triploblastic animals with characteristic muscular foot. Examples, clams, snails, squids, octopi.
- *MONAXONIDA*, mŏnaksŏn′ĭdā (G. *monos*, alone + *axon*, axis) 419
  - An order of *Porifera* with monaxon but no tetraxon spicules.
- MONILIFORM, mŏnĭl′ĭfôrm (L. *monile*, necklace + *forma*, shape) 774
  - Constricted at regular intervals, giving the appearance of a chain of beads.
- MONIST, mŏ′nist (G. *monos*, alone), definition of 175
- MONITOR, mŏ′nitôr (L. *monitor*, one who reminds) 654
- MONKEYS, mung′kis (origin unknown; prob. Fr. G. *mimo*, an ape) 659
- MONOCOTYLEDONS, mŏnokŏt′ĭlēdonz (G. *monos*, alone + *kotyledon*, a cup-shaped hollow) 227
  - Plants having one embryo lobe.
- MONOCYST, mon′ōsist (G. *monos*, single + *kystos*, a bag), definition of .. 153
- *MONODELPHIA*, mŏnŏdĕl′fĭă (G. *monos*, single + *delphis*, womb) 426, 431, 658
- MONODINE (G. *monodia*, a solo, lament) 143
- *MONODON* MONOCEROS, mon′ōdon mōnŏ′serus (G. *monodous*, one-toothed + *monokeros*, a unicorn) ... *662*
- MONOECIOUS, mŏnē′shŭs (G. *monos*, single + *oikos*, house), definition of. 217
- *MONOGENEA*, mŏnōjē′nia (G. *monos*, single + *genos*, kind) 420
  - An order of Trematodes which develop direct from the egg.
- MONOGENETIC, mŏn′ôjĕnĕt′ĭk (G. *monos* + *genesis*, descent), ... 288
  - Definition of 403
  - Direct asexual reproduction.
- MONOPHYLETIC, mŏn′ôfīlĕt′ĭk (G. *monos* + *phyle*, tribe), definition of. 403
- MONOPHYODONT, mŏnōfī′ōdont (G. *monos* + *phyein*, to produce + *odous*, tooth), definition of 733
- MONOSACCHARIDE, monosăk′arid (G. *monos*, alone + L. *saccharum*, sugar) 187
- *MONOSIGA*, definition of 151
- *MONOTREMATA*, mon′ohtremm′atah (G. *monos*, one; *trema*, opening) ... 426
  - Definition of 656
- MONRO—
  - Foramen of 839
  - Sulcus of, definition of 845
- MORAL SENSE, definition of 183
- MORGAGNI'S SINUS, definition of .. 764

MORPHOLOGY, môrfŏl′ôjĭ (G. *morphe*, form + *logos*, discourse) 31
Science of form and structure of animals and plants.
MORULA, môr′ūlă (L. *morum*, a mulberry), definition of 106, 447
Definition of, in protozoans 182
Of rabbit *621*
MOSAIC IMAGE, definition of 321
MOSQUITOES AND MALARIA 134
MOSS-ANIMALS, definition of 310
MOSSES 215
MOSS PLANTS, definition of 203
MOTILE, mō′til (L. *motus*, moved) .. 225
MOULT, mōlt (L. *mutare*, to change) .667
Definition of 330
MUCOSA, mūkō′să (L. *mucus*, mucus) 49
A membrane secreting mucus.
MUCOSUM 665
MUCOUS GLANDS 46
MUD-EEL *649*
MUD-PUPPIES *647*
Definition of 649
MÜLLER, JOHANNES. 380, 386, 388, 415
MULTANGULUM, mŭltăng′gūlum (L. *multus*, many + *angulus*, angle) ... 709
Two carpal bones, the trapezium and the trapezoid.
MUSCA DOMESTICA *369*
MUSCI, mŭs′kĭ (L. *muscus*, moss) 215
MUSCLE, mŭs′l (L. *musculus*, muscle)
Circular *49*
Longitudinal *49*
Plate, definition of 516, 591
MUSTELIDS, mŭs′telĭds (L. *mustela*, a weasel, also kind of fish), definition of *735*
MUSTELIS, definition of 641
MUTATION THEORY, mūtā′shŭn (L. *mutare*, to change), definition of 164, 404
MUTTKOWSKI 138
MYCELIUM, mīsē′lĭŭm (G. *mykes*, fungus), definition of 208
MYCETES, mīsē′tēz (G. *myketes*, a bellower), definition of 190
MYCETOMA, mīsētō′ma (G. *mykes*, fungus + *oma*), definition of 214
MYCOSIS, mīkō′sis (G. *mykes*, fungus + *osis*), definition of 214
MYELENCEPHALON, mī′ĕlĕnsĕf′ălŏn, (G. *myelos*, marrow + *en*, in + *kephale*, head), definition of 845
MYELIN, mī′ēlĭn (G. *myelos*, marrow), definition of 114
MYELOCOELE, mī′ēlōsēl (G. *myelos*, marrow + *koilos*, hollow), definition of 511
MYLOHYOID, my′lowhigh′oid (G. *myle*, mill; *upsilon*, the letter *y*) *80*, 831
MYOCARDIUM, mī′okâr′dĭŭm (G. *mys*, muscle + *kardia*, heart) 469
Definition of 529
MYOCOELE, mī′osēl (G. *mys* + *koilos*), definition of 502
MYOCOMMATA, mī″okŭm′ătă (G. *mys*, muscle; *komma*, that which is cut off), definition of 592
MYOEPICARDIAL MANTLE, mī′oĕpĭkâr′dĭăl (G. *mys* + *epi*, upon + *kardia*, heart), definition of 777
MYOSITIS, mīōsī′tis (G. *mys*, a muscle + *itis*), definition of 303
MYOTOME, my′ohtome (G. *mys*, muscle; *tome*, cutting), definitions of 502, 591
MYRIOPODA, mĭrĭŏp′ōdâ (G. *myrioi*, 10,000 + *pous*, foot) 422, 429, 430
MYSTACOCETI, mis′tăcōsē′tĭ (G. *mystos*, mustache + *ketos*, whale) 426, 663
An order of cetaceans, including whalebone whales.
They are toothless but have baleen in upper jaw.
MYTILUS, mit′ilus (G. *mytilos*, a sea-mussel) 155
MYXINE GLUTINOSA, miksī′nē glūtinō′sa (G. *myxa*, slime + L. *glutinosus*, gluey) *641*
MYXINOIDEA, mik′sinoid′ia (G. *myxa*, slime + *eidos*, resemblance) . 424
MYXIPTERYGIUM 707
MYXOPHYCEAE, miksōfī′sēē (G. *myxa*, mucus + *phykos*, sea weed), definition of 204
MYXOSPORIDIA, mik′sōspōrid′ia (G. *myxa*, mucus + *spora*, seed) 419
An order of *Neosporidia*.
Definition of 153

NAGELI 404
NAIL, nāl (A. S. *naegel*, nail) *669*
The terminal horny plate of finger or toe.
NAIS 283
A sub-class of *Oligochaeta*.
NAPLIUS *327*
NARCOMEDUSAE, nâr′kōmĕdū′sē (G. *narke*, numbness + L. *medusa*) 419
An order of *Hydrazoa*.
NARES, nā′rēs (L. nostril) .. 62, 582, 869
NARWHAL, nâr′hwal (Icel. *nāhvalr*, a corpse-whale) *662*
NASAL, nā′zăl (L. *nasus*, nose) .. 73, 617
NAVEL, nā′vel (A. S. *nafele*, navel) . 632
Place of attachment of umbilical cord.
NAVICULARE, navĭ′k′ūlārē (L. *naris*, ship) 709
The scaphoid radiale of mammalian carpus.

NEANDERTHAL MAN *399, 400*

NEBULIFERA, nebūlif'era (L. *nebula*, cloud + *ferre*, bear) *156*

NECATOR AMERICANUS 303

NECROBIOTIC GLANDS, nek'rōbīot'ĭk (G. *nekros*, a dead body + *bios*, life), definition of 673

NECTAR, nĕk'tăr (G. *nektar*, nectar).364

  Sweet substance secreted by special glands, the nectaries, in plants.

NECTONEMA AGILE (G. *nektos*, swimming) *308*

NECTOPHORES, nĕk'tōfōrs (G. *nektos*, swimming + *pherein*, to carry)....*255*

NECTURUS MACULATUS, nectūr'us (G. *nektos*, swimming; *oura*, tail).*649*

NEENCEPHALON 855

NEMATHELMINTHES, nĕm'âthelmĭn'thēz (G. *nema*, thread + *thelmins*, a worm)...........265, 285, 428

NEMATOCYST, nĕm'ătosĭst (G. *nema*, thread + *kystis*, bladder)..........348

  A stinging cell.

NEMATOMORPHA (G. *nema*, thread + *morphe*, form)....306, 308, 424, 432

NEMERTINAE, nĕmĕrtī'ni (G. *nemertes*, true)...............306, 424, 432

  A group of worms of uncertain position.

NEOCERATODUS FOSTERI *646*

NEOPALLIUM, nē'opăl'ĭŭm (G. *neos*, young + *pallium*, cloak), definition of 843, 848

NEORNITHES, nēōr'nithēz (G. *neos*, new + *ornis*, bird)...............425

  A sub-class of *Aves*. Recent.

NEOSPORIDIA, nēōspōrĭd'iă (G. *neos* + *spora*, seed)...........143, 153, 149

  A sub-class of *Sporozoa*.

NEOTHALAMUS, nēōthăl'ămŭs (G. *neos* + *thalamos*, a chamber), definition of 851

NEOTONY, definition of.............648

NEPHRIDIA, definition of 266

  Views as to relations............807

NEPHRIDIOPORE, nefrĭd'iopōr (G. *nephros* + *poros*, a passage).......*259*

NEPHRIDIUM, nĕfrĭd'ĭŭm (G. *nephros*, kidney) *259*, *273*

NEPHROSTOME, neff'rowstone (G. *nephros*, kidney; *stoma*, mouth) ... .64, *259*, 505

NEPHROTOME, neff'rowtome (G. *nephros*, kidney; *tome*, cutting), definition of 503, 593

NEREIS PELAGIA, nē'reis (G. *nereis*, a sea-nymph) *280*

NERVE ARC, nĕrv (L. *nervus*, sinew), definition of 177

NERVE, artery and vein............ *58*

  Centers 115

  Vagus *65*

NERVOUS ACTION, experiment of..521

NERVOUS SYSTEM OF FROG....*65*, 66

  Of amphibia ....

  Of aves ....

  Of fishes ....

  Of insects .... } 360

  Of mammals ....

  Of reptiles ....

NERVURES, nĕr'vūr (L. *nervus*, sinew) *335*

  One of the rib-like structures which support the membranous wings of insects.

NEURAL, nū'ral (G. *neuron*, nerve)..

  Arch 72, 681

  Canal 66

  Crests 467

  Folds 460, 563

  Groove 460, 563

  Plate 459

  Ridge 562

  Tube 466

NEURENTERIC CANAL, nūr'ĕntĕr'ĭk (G. *neuron*, nerve + *enteron*, gut), definition of 475

NEUROBLASTS, nū'roblăstz (G. *neuron* + *blastos*, bud)...........280

  Primitive nerve cells.

NEUROCHORD, nū'rokord (G. *neuron*, nerve + *chorde*, string of gut), definition of 274

NEUROGLIA, nū'roglē'ă, nūrōg'lĭă (G. *neuron* + *glia*, glue) 836

  Supporting tissue of nerve cells and nerve fibers.

NEUROLOGY (G. *neuron* + *logos*), definition of 31, 40

NEUROMASTS, nū'romăsts (G. *neuron* + *mastos*, knoll).................879

  Groups of sensory cells in the lateral line of fishes.

NEUROMERE (G. *neuron* + *meros*, a + *meros*, part)..............473, 478

  A spinal segment.

NEURON (G. *neuron*, nerve), definition of 114

NEUROPORE, nū'rōpōr (G. *neuron* + *poros*) 466, 474, 565

  The anterior opening of the neurocoele to the exterior.

NEUROPTERA, nū'rŏp'tĕră (G. *neuron* + *pteron*, wing) 423

  Animals having wings with a network of nervures.

  An order of *Neuropteroidea*.

NEUROPTEROIDEA, nūrŏpteroi'dēâ (G. *neuron*, nerve + *pteron*, wing).423

  A sub-class of *Pterygogenea*.

NEWMAN, H. H...............397, 543

NEWTS 648

NICTITATING MEMBRANE, nik'titay'ting (L. *nicto*, wink).......... *45*

NIDAMENTAL GLANDS, nĭd'ămēn'tăl (L. *nidus*, a nest) 86, 816
Glands which secrete material for an egg-covering.
NIGHTSHADE, nīt'shād (A. S. *niht scada*, nightshade) *243*
NOCARDIA BOVIS *214*
Actinomyces *214*
NOCARDIOSIS 214
NOCTILUCA, nŏk'tĭloo'kă (L. *nox*, night + *lux*, light) *150*, 151
Phosphorescent forms.
NODE, nōd (L. *nodus*, knob) *203*
Of Ranvier 114
NODOSE GANGLION, nōdōs (L. *nodus*), definition of 886
NOSEMA APIS, nō'sēma (a new Latin word) *153*
Bombycis 153
NOTABLE MEN IN BIOLOGY......386
NOTIDANID, nōtĭd'anĭd (G. *notidanos*, with sharp-pointed dorsal fin) 786
A sub-order of sharks with more than five gill-clefts.
NOTOCHORD, no'toekord (G. *notos*, back; *chorde*, string).........562, 639
NOTOGENESIS, nō'tôgĕn'ĕsĭs (G. *notos* + *genesis*) 563
NOTORYCTES, nōtôriktēz (N. L. same word, a generic name)......876
NOTOTREMA, nōtōtrē'ma (G. *notos* + *trema*, perforation) 816
A genus of South American toads with dorsal brood-sac.
NOTUM, nō'tŭm (L. *notum*, back)...336
The dorsal portion of an insect segment.
NUCELLUS, nūsĕl'ŭs (L. dim. of *nux*, nut) *239*
The central region and chief part of an ovule.
NUCHAL, new'kal (L. *nucha*, nape of the neck) *702*
Brain flexure 837
NUCLEAR SAP, definition of........ 90
NUCLEI, OF BRAIN................847
NUCLEOLUS, nūklē'ôlŭs (L. dim. of *nucleus*, kernel) 89
A rounded mass in nucleus.
NUCLEOPLASM, nū'klĕôplăzm, definition of 89
NUCLEUS, nū'klēŭs (L. *nucleus*, kernel) 89
A complex spheroidal mass essential to the life of a cell.
NURSE CELLS, definition of........443
NUTRIENT 63
NUTRITIVE CELLS, definition of....811
Pole, definition of...............105
NUX VOMICA *235*
NYCTERIDIPHILUS HEXACTENUS, nĭk'terĭdif'ĭlŭs (G. *nykteros*, by night + *philos*, friend) *350*
NYMPH, nĭmf (G. *nymphe*, bride) 331, 348
A stage following the larval in insect metamorphosis.
NYMPHOMORPHA 422
An order of *Pantopoda*.

OBELIA, obē'lia (G. *obelos*, a spit)..252
A genus of polyps.
OBJECTIVE, definition of...........173
OBJECT OF SCIENCE.............. 35
OBLIQUE SEPTUM, definition of....757
OBLIQUUS, oblī'kwus (L. *oblique*)... 79
OBSTETRICAL TOAD, obstet'rikal (L. *obstetricus*, pertaining to midwifery, from L. *ob*, before, and *stare*, to stand) *650*
OBTURATOR, ob'tūrātor (L. *obturare*,.. to stop up) 83
Foramen *703*
OCCIPITAL CARTILAGE 615
OCCIPUT, ok'siput (L. *occiput*, the back of the head, from *ob*, over against + *caput*, head)...........615
OCELLI, plural of *ocellus*, definition of 328
OCELLUS, ōsel'us (L. *ocellus*, a bulb or little eye) *341*
OCULINA SPECIOSA, ok'ulī'na (L. *oculus*, an eye)..................*257*
The typical genus of the family *Oculinidae*.
OCULOMOTOR, ok"ūlōmō'tor (L. *oculus*, eye + *moveo*, to move)..... 68
Moving the eyeball.
ODONATA, ōdōnā'tâ (G. *odous*, tooth) 423
An order of *Libĕlluloidea*.
ODONTOBLASTS, ōdŏnt'ōblasts (G. *odous*, tooth + *blastos*, a germ)....732
Embryonic cells to form future teeth.
ODONTOCETI, ōdŏntōsē'tī (G. *odous*, tooth + *ketos*, a whale)......426, 662
A sub-order of *Cetacea*.
ODONTOID, ōdŏnt'oid (G. *odous* + *eidos*, resemblance, tooth-like)......517
Process 684
OESOPHAGUS, ēsŏf'agus (G. *oesophagus*, gullet) 49
The canal through which food passes to the stomach.
OIDIA, ōĭd'ĭa. See *oidium*..........210
OIDIOMYCOSIS, ōĭd'ĭōmykō'sĭs (G. *oidium* + *mykos*, a fungus + *osis*) .212
The presence in the body of fungi as parasites.
OIDIUM, ōid'ium (G. *oôn*, egg + dim. suffix, *idion*).................***211***
A genus of parasitic fungi.

OIKOPLEURA, oikoplū′ra (G. *oikos*, house + *pleura*, side) 544
One of the order *Larvacea*.
OKEN, ō′kên 415
A German naturalist, 1779-1851.
OLECRANON, ōlĕkrā′non (G. *olekranon*, point of the elbow) 711
Pertaining to a process of the ulna; the elbow.
OLFACTORIUS LATERALIS NUCLEUS 849
OLFACTORY, ôlfak′tŏrĭ (L. *olere*, smell) 62, 68
  Capsules 540
  Duct 870
  Pits 581
  Placodes 581
  Recess 570
OLIGOCHAETA, ol′igōkē′ta (G. *oligos*, few + *chaite*, hair) 283, 421
A class of *Annelida*.
OLIVE OF SPINAL CORD. 841
OLMS (German name for the white, blind, cave mud-puppies) 649
OMASUS, ômā′sŭs (L. *omasum*, paunch) 745
OMENTUM, ôment′ŭm (L. *omentum*, a fold) 537, *726*, 746
OMMATIDIUM, ōm′atĭd′ium (G. *omma*, eye) *322*
OMNIVOROUS, omnĭv′ōrus (L. *omnis*, all + *voro*, eat) *736*
Eating both plant and animal food.
OMOSTERNUM, ō′môstĕr′num (G. *omos*, shoulder + *sternon*, breast) 76, *701*
OMPHALOMESENTERIC VEIN, ŏm′fălômĕs′ĕnter′ic (G. *omphalos*, navel + *mesenteron*, mid-gut) *469*
OMPHALOMESENTERIC VS. VITELLINE, vītĕl′īn (L. *vitellus*, yolk) . . .483
ONISCUS ASCELLUS, ōnis′kus ăsĕl′us (G. *oniskos*, a wood-louse) *326*
Typical genus of *Oniscidae*.
ONYCOPHORA, onikof′ōra (G. *onos*, a claw or nail + *pherein*, to bear) 421, 428
OOCYST, ō′ōsist (G. *oon*, egg + *kustis*, bladder) 132
OOCYTE, ō′ōsīt (G. *oon* + *kytos*, cell) 100, *443*
OOECIUM, ōē′shium (G. *oon*, egg + *oikos*, house) 310
A brood-pouch.
OOGENESIS IN EARTHWORM, ōōjen′esis (G. *oon* + *genesis*, descent) 279
OOGONIA, plural of oogonium. 100
OOGONIUM, ōōgō′nium (G. *oon* + *gonos*, offspring) 298
OOKINETE, ōōkinēt′ (G. *oon* + *kinein*, to move) .132
OOSPORA BOVIS, ō′ōsporă (G. *oon* + *sporos*, seed) *214*
OOSPORE (same as oospora) . . .*151*, *187*
OOTYPE, ō′ōtype (G. *oon* + *type*, place) *296*
Place where the shell is formed.
OPALINA, ōpalī′na (like opal) *154*
OPAQUE, ōpāk′ (L. *opacus*, darkened) 437
Impervious to light.
OPEN CIRCULATION, definition of. .270
OPERCULAR TUBE, definition of. . . .586
OPERCULUM, ôpĕr′kūlŭm (G. *operculum*, a lid) *216*
  Of plants 220
  Of tadpole 549, 586
OPHIDIA, ōfid′ia (G. *ophis*, serpent + *eidos*, form) 425, 654, 704
OPHIUROIDEA, of′iūroi′dēa (G. *ophiouros*, serpent-tailed) 420, 428
OPHTHALMIC, ofthal′mic (G. *opthalmikos*, of or for the eyes) 319
OPILIONES, ōpiliō′nez (L. *opilio*, a shepard) 422
An order of *Arachnids*.
OPISTHOBRANCHIA, ōpisthōbrang′kia (G. *opisthe*, behind + *branch*, gills) 421
OPISTHOCOELOUS, ōpisthōsē′lus (G. *opisthe* + *koilos*, hollow), definition of 683
OPISTHODELPHYS, ōpisthōdel′fis (G. *opisthen*, behind + *delphis*, dolphin) 816
OPISTHOGONEATA (G. *opisthe* + *gone*, genitalia) 422
A subclass of *Myriapoda*.
OPISTHOMI, opisthō′mi (G. *opisthen*, behind + *omos*, shoulder) 645
OPISTHORCIS FELINEUS, opisthor′kīs felin′eus (G. *opisthe* + *orchis*, testicle) *292*
  Noverca *292*
  Sinensis 293
OPISTHOTIC, ŏp′isthŏt′ik (G. *opisthe* + *ous*, ear) *692*
OPOSSUM, ōpos′um 657
OPOTERODONTS, ōpot′erōdonts (G. *opoteros*, either + *odous*, tooth) 706
OPSONIN, ŏp′sōnin (G. *opsonein*, to cater), definition of 200
OPTIC CHIASMA (G. *opsis*, sight) . .571
  Lobes 512
  Nerve 70
  Pedicle 875
  Stalks 478
  Vesicles 474
OPTICAL SECTION *279*
OPTIMUM, ŏp′timŭm (L. *optimus*, best), definition of 129
OPTOCOELE, ŏp′tôsēl (G. *opsis*, sight + *koilos*, hollow) 490
ORAL OPENING (L. *os*, mouth) 48
  Plate 493, 585

ORANGE BLOSSOM *242*
ORANG-UTAN, ōrang′otan (Malay, *orang*, man + *utan*, woods) 660
ORBICULARIS MUSCLES, ôrbĭk′ularis (L. *orbis*, an orb) 832
ORBITAL GLAND, or′bĭtăl (L. *orbita*, circuit) 742
ORDERS IN LIVING THINGS 415
ORGAN (L. *organum*, an implement). 46
  Balancing 323
  Of equilibrium 323
  Floral *242*
ORGANIC, definition of 94
  Pertaining to living organisms.
ORGANISM, definition of 108, 119
ORIGIN OF MUSCLE 78
  Of species 403
ORNITHOLOGIST, ôr′nĭthŏl′ōjist (G. *ornis*, bird + *logos*, discourse) 418
  A student of birds.
ORNITHORHYNCHIDAE, or′nithōring′kide (G. *ornis*, bird + *rugxus*, beak) 657
ORNITHORHYNCHUS ANATINUS .. *656*
ORTHOGENESIS, or′thojĕn′esis (G. *orthos*, straight; *genesis*, descent), definition of 404
ORTHONECTIDAE, or′thonĕk′tĭdāy (G. *orthos*, straight + *nektys*, dead body) 306
ORTHOPTERA, orthop′tera (G. *orthos*, straight; *pteron*, wing) 334, 423
  An order of *Orthopteroidea*.
ORTHOPTEROIDEA, orthop′teroid′ea. 423
  A subclass of *Pterygogenea*.
OS CLOACAE, ōs klōā′kā (L. *cloaca*, a sewer) 706
  Entoglossum, ĕntōglŏs′sum (G. *entos*, within; *glossa*, tongue) .. 740
OSMOSIS, ŏsmō′sĭs (G. *othein*, to push) 37
OSSICLES, ŏs′sicles (L. dimin. of *os*, bone) 318
OSSIFICATION, os′sĭfĭkā′shŭn (L. *os* + *fio*, to become) 74
  Centers *517*
OSTARIOPHYSI, ostā′riōfī′sī (G. *ostarion*, a little bone + *phusa*, bladder) 643
OSTEOBLASTS, ŏs′tēoblăsts (G. *osteon*, bone + *blastos*, a bud) 112
  Primitive bone cells.
OSTEOLEPIDA, ŏstēolĕp′idâ (G. *osteon* + *lepis*, a scale) 642
OSTIA, ŏstĭa (L. *ostium*, a door) 339
OSTIUM OF OVIDUCT *440*
  Tubae (L. *tuba*, a horn) 824
  Tubae abdominale 808
OSTRACODA, ostrakō′da (G. *ostrakodas*, like a shell) 421
  A sub-class of *Crustacea*.
OSTRACODERMI, os′trakōder′mĭ (G. *ostrakodermos*, bony skin) 646
OTIC, ŏ′tĭk (G. *ous*, ear) 73
OTOCYST, ō′tôsĭst (G. *kystis*, bladder) definition of 323, 581
OTOLITHS, ōtôlĭths (G. *ous*, ear + *lithos*, stone), definition of 868
OVARIAL CORDS, ōvăr′ial (L. *ovarium*, an ovary) 520
OVARIOLES, ôvăr′iōls (L. *ovarium*), definition of 344
OVARY, ōvărĭ (L. *ovarium*) 47
OVERTON 206
OVIDUCTS, ō′vĭdŭkts (L. *ovum*, egg + *duco*, to lead) 47, 86
OVIPOSITOR, ō′vĭpoz′ĭtor (L. *ovum*, egg + *pono*, to place) 337
OVULE, ōv′ūle (L. dim. of *ovum*, egg) 226, *242*
OVULIFEROUS, ōvŭlĭ′fĕrŭs (L. *ovum*, egg + *fero*, to bear) *239*
OVUM AS USED IN MAMMALIAN EMBRYOLOGY (G. *oon*, egg) 624
OWEN 380
OXIDATION, ŏksĭdā′shŭn (G. *oxys*, acid) 30, 38, 129
OXYTRICHA, oksit′rika (G. *oksus*, sharp + *trix*, hair) 154
OXYURIS INCOGNITA, oksiū′ris (G. *oksus* + *oura*, tail) *301*
  Incognitus, unknown.
  Vermicularis (L. *vermis*, a worm) *.301*

PACINIAN CORPUSCLE, pāsĭn′ĭan cōr′pusl (L. *corpusculus*, a small body) *864*
PADDLE FISHES *643*
PAD, SUBARTICULAR, sŭb′artĭk′ŭlăr (L. *sub*, below + *articulus*, joint) .. 46
PAEDOGENESIS, pē′dōgĕn′esis (G. *pais*, child; *genesis*, descent) 345, 648, 100
PALAEENCEPHALON, pā′lēĕnsĕf′alŏn (G. *palaios*, ancient + *en*, within + *kephalos*, head, i.e., primitive brain) 855
PALAEMON, pālē′mon (G. *palaimon*, a sea god) *325*
PALAEONTOLOGY, pā′lēŏntŏl′ogy (G. *palaios*, ancient + *ons*, being + *logos*, discourse) 32, 393-401
  Chart 394, 395
PALAEOSPONDYLIDAE, pālēōspŏndĭ′lidāy (G. *palaios*, ancient + *spondulos*, vertebra) 646
PALAEOTHALAMUS, pā′lēōthăl′amus (G. *palaios*, ancient + *thalamos*, a receptacle) 851
PALAEOZOIC, pā′lēōzō′ĭk (G. *palaios*, ancient; *zoon*, animal) *395*
PALAMEDEIDAE, pal′amēdē′idē (G. *palme*, palm-webbing of foot) 719

PALATAL GLANDS, păl'ătăl (L. *palatum*, palate) 742

PALATE, pălăt (L. *palatum*, palate).730

PALATINE, păl'atēn (L. *palatum*, palate) 72, 616, 617

PALATO-QUADRATE, păl'ăto-quawdrāte (L. *palatum* + *quadratus*, squared) ....
  Where formed 616

PALLIUM, pahl'eeum (L. cloak.) 839, 848

PALPUS, pălpus (L. *palpare*, to feel).335

PALUSTRIS, pălŭs'tris (L. *palus*, a swamp) *701*

PANCREAS, pan'kreeass (G. *pan*, all; *kreas*, flesh) 48
  Development of 589
  Duct of 48
  Juice of 50

PANDER, NUCLEUS OF............436

PANIZZA'S FORAMEN, definition of.786

PANORPATAE, panorpā'tē (G. *pan*, all + *arpe*, sickle)....................423
  An order of *Panorpoidea*.

PANORPOIDEA, panorpoi'dea (G. *pan*, all + *arpe*, sickle)............423
  A sub-class of *Pterygogena*.

PANTOPODA, pantop'ōdâ (G. *pan*, all + *pous*, foot)...............422, 430

PAN-TROGLODYTES, pantrog'lōdītes (G. *pan*, all + *troglodytes*, cave dweller) *660*

PAPILLARY LAYER, păp'ĭllărĭ (L. *papilla*, a pimple)...............

PARA, par'ah (G. prefix, beside, near).

PARABRONCHI, pā'răbron'kĭ (G. *para*, near + *brongchos*, windpipe)......766

PARACHORDAL PLATES, pārăkōr'dal (G. *para*, near + *chorde*, a cord) *539*

PARACONE, pā'rakōn (G. *para*, near + *konos*, a cone)....................*736*

PARACORDAL (same as parachordal) 614

PARAGLOSSAE, părâglŏs'ā (G. *para*, near + *glossa*, tongue)........*354*, 740

PARAGONIMUS WESTERMANNI, părigŏn'imus (G. *para* + *gonimus*, with generative power)............291

PARAGORDIUS VARIUS (G. *para* + L. *gordius*, complex from Gordian knot) *308*

PARALLEL INDUCTION THEORY, definition of 397

PARALLELIST, definition of........175

PARAMOECIUM, paramē'sium (G. *paramekes*, of longish shape)......138

PARAMYLUM, părā'mylŭm (G. *para*, beside + *amylum*, starch).........128

PARAPHYSIS, paraff'eesis (G. *para*, beside; *phyo*, produce)....*217*, 571, 856

PARAPLASMIC, părăplăs'mic (G. *para*, beside + *plasma*, something moulded) 92

PARAPODIA, părăpō'dĭă (G. *para*, beside + *pous*, foot)..............283

PARASITES, păr'ăsīt's (G. *para*, beside + *sitos*, food)............37, 208

PARASITIC CRUSTACEA, krŭs'tāshya (L. *crusta*, a shell)..........325
  Nematodes *305*
  Worms *303*

PARASPHENOID, părăsfēn'oid (G. *para*, beside + *sphen*, wedge + *eides*, like) 73, 617

PARATERMINAL BODY, părătĕr'mĭnăl (G. *para*, beside + *terminus*, the end) *842*

PARATHYROID BODY, părăthī'roid (G. *para*, beside + *thyreos*, a shield) 744

PARATROPHIC, părătrō'fic (G. *para*, beside + *trophe*, nourishment).....191

PARENCHYMA, părĕn'kĭmă. See page 757 258
  Cortical 230
  Porous 235
  Where found 233

PARENCHYMATOUS ORGANS, definition of 757

PARIETAL, părī'ētăl (L. *paries*, wall)....................73, 269, 617
  Foramina 858
  Muscles 826
  Organs *852*

PARMELIA, pârmē'liâ (G. *parme*, a small shield) 205
  A species of lichen.

PAROTID, parot'id (G. *para*, beside; *ous*, ear).

PAROVARIAL CANAL, păr'ōvār'ĭal (G. *para* + L. *ovarium*, an ovary) .816

PAROVARIUM (G. *para* + L. *ovarium*) *441*

PARS OPTICA, pâhrs ŏp'tika (L. *pars*, part + *opticus*, pertaining to vision) 852

PARTHENOGENESIS, pahr'thĕnōjĕn'esis (G. *parthenos*, a virgin + *genesis*, descent)....................100, 344

PARTHENOGONADIA, pahr'thĕnōgonād'iă (G. *parthenos*, virgin + *gonos*, offspring)............130, 150.

PARTIAL SEGMENTATION, definition of 106

PARTURITION, pahr'tūrĭ'shun (L. *parturire*, to be in labor)..........620

PASSERIFORMES, pas′erifôr′mez (L. *passer*, sparrow + *formes*, form)...425
  Sparrow-like birds. More than one-half of all birds belong to this group. There are 64 families.
PASSIVE POLE, definition of........105
PASTEUR, LOUIS 36, 382, 388
PASTEUR'S SOLUTION 189
  A bacteriologic culture-fluid consisting of 100 parts water, 10 parts sugar, and 1 part each ashes of yeast and ammonium carbonate.
PATELLA, patell′ah (L. a small pan or dish) 710
PATELLINA (L. *patellae*, a small dish) *156*
  A species of *Vorticella*.
PATENS (L. *pateo*, to lie exposed)...*155*
  A species of *Condylostoma*.
PATHOGENIC, păth′ogĕ′nic (G. *pathos*, suffering + *genos*, offspring).......141
  Fungi 209
  Protozoa 142
PATHOLOGY, păthŏl′ojĭ (G. *pathos*, suffering + *genos*, offspring).......141
PATTERSON 466
PATTON 638
PAUNCH, pânch (L. *pantex*, belly)..745
PAUROPODA, pârop′ōdâ (G. *pauros*, small + *pous*, foot) 422
  An order of *Progoneata*.
PEA FRUIT DEVELOPMENT.......*245*
PEAT-MOSSES, definition of........*215*
PEBRINE, pĕb′rĭn (F. *pébrine*, disease of silkworm)............153, 333
PECTEN, pak′ten (L. comb).........*874*
PECTINEAL, pek′tinee′al (L. *pecten*, comb) *701*
  Process 705
PECTINEUS, pĕktĭnē′us (L. *pecten*, comb) 83, 829
PECTINIBRANCHIA, pek′tĭnĭbrang′kĭâ (G. *pecten*, comb + *branchia*, gills) 421
  An order of *Gastropoda*.
PECTORAL, pek′toeral (L. *pectoralis*, referring to the chest)........73, 531
  Girdles *699, 700*
PECTORALIS, pĕktoeral′is (same as pectoral) 79, 829
PEDICEL, pĕd′isĕl (L. *pediculus*, a small foot) 218
PEDICELLINA, pĕdĭselē′na (N. L. *pedicellus*, pedicel) 310
PEDICLE, OPTIC, pĕd′ikle (L. *pediculus*) 875
PEDICULATI, pĕdĭ′cūlā′tī (L. *pediculus*, a little foot)................645
PEDICULOIDES VENTRICOSUS, pĕdĭkūloid′ēz (L. *pediculus*, louse).350
PEDIPALPI, pĕdĭpăl′pĭ (L. *pes*, foot + *palpus*, palp) 422
  An order of *Lipoctena*.
PEDUNCLE, pĕdŭng′kle (L. *pedunculus*, a small foot)..................310
  Anterior 859
  Cerebellar 512
  Cerebral 512, 839, 845
PELARGONIUM, pĕlârgō′nĭum (G. *pelargos*, stork, from the resemblance to a stork's bill)...........*234*
  A species of *Geranium*.
PELECYPODA, pĕlēsĭp′ōdâ (G. *pelekus*, ax + *pous*)..........421, 429
PELLICLE, pĕl′ĭkle (L. *pellicula*, a small skin) 138
PELLUCID, pĕlūsĭd (L. *pellucida*, transparent) 439
PELVIS, pĕl′vĭs (L. *pelvis*, basin, the pelvis) 73, *701*
PELVIC GIRDLE *705*
PENETRATION PATH, definition of.551
PENIS, pee′nis (L. male copulatory organ) *820*
PENNATULA SULCATA, pĕnăt′ūlā (L. *pennatus*, winged).............*256*
PENNATULACEA, pĕnătūlā′sēâ (L. *pennatus*, winged) 420
  An order of *Alcyonaria*.
PENTADACTYL, pĕn′tădăk′tĭl (G. *pente*, five + *daktylos*, finger).....646
PENTASTOMOIDEA, pĕn′tastōmoi′dēă (G. *pente*, five + *stoma*, mouth)....422
  An order of *Linguatulida*.
PENTRICHA 154
PEPPERMINT *235*
PEPSIN, pĕp′sin (G. *pepsis*, a digesting) 50
PEPTONES, pep′tōns 50, 268
PERCEPTION (L. *per*, through + *capio*, to grasp), definition of......177
PERCESOCES, persĕs′ōsēz (G. *perke*, perch + *esox*, a kind of pike)......643
PERENNIALS, pĕrĕn′nĭals (L. *per*, through + *annus*, year)...........232
PERENNIBRANCHII, pĕrĕn′nĭbrang′kei (L. *per* + *annus* + G. *brangchia*, gills) 649
PERENNIBRANCHS, pĕrĕn′nibrănks (L. *per* + *annus* + G. *brangchia*).760
PERFECT FLOWERS, definition of..228
PERIANTH, pĕr′ĭănth (G. *peri*, around + *anthos*, flower) *203, 242*
PERIBLAST, pĕr′ĭblăst (G. *peri*, around + *blastos*, a bud), definition of 445
PERIBLEM, pĕr′ĭblĕm (G. *peri*, around + *blema*, a coverlet)...............228

PERICARDIAL CAVITY, per′ēkar′dĕal (G. *peri*, around + *kardia*, heart) 470
  Region 536
  Sinus 319
PERICARDIUM, pĕrē′kar′dēum.47, *55*, 520
PERICHAETIUM, perikē′teum (G. *peri*, around + *chaite*, loose hair) *216*, 218
PERICHONDRIUM, perikŏn′drēum (G. *peri*, around + *chondros*, cartilage). 111, 681
PERIDERM, pĕr′idĕrm (G. *peri* + *derma*, skin) 666
PERIDINIUM, pĕrĭdĭn′ĭum (G. *peridines*, whirled around) 151
PERIDURAL, pĕridūr′al (G. *peri*, around + L. *dura*, hard), definition of 838
PERILYMPH, pĕr′ilymph (G. *peri*, around + L. *lympha*, water), definition of 868
PERIMYSIUM, pĕrimys′ium (G. *peri*, around + *mys*, muscle) 828
PERINEAL FOLD, pĕr′inē′al (G. *perinaion*, region between anus and scrotum) 758
PERIOSTEUM, pĕriŏs′tēum (G. *peri*, around + *osteon*, bone), definition of 112
PERIPATUS, peripā′tŭs (G. *peripatos*, walk about) 429
PERIPHERAL, periff′eral (G. *peri*, around; *phero*, bear) 274
  Nervous system 66, 67
  Segmentation 106
PERIPHYLLA HYACINTHIA, perifil′a (G. *peri*, around + *phyllon*, leaf) *256*
PERISARC, pĕr′ysâhrk (G. *peri* + *sarx*, flesh) 252
PERISSODACTYLA, pĕrĭsōdak′tilâ (G. *perissodaktulos*, more than regular number of fingers or toes) 426, 662
PERISTALSIS, per′istăl′sis (G. *peri* + *stellein*, to place), definition of....270
PERITONEAL, perr′itoenee′al, -um (G. *peri*, around; *teino*, stretch)....536
PERITONEUM, perr′itoenee′um. (See above) 47, 727
PERITRICHA, perrit′rīka (G. *peri* + *thrix*, hair) 419
PERIVITELLINE SPACE, pĕri′vitĕl′ĭn (G. *peri* + *vitellus*, yolk) 551
PERLOIDEA, pĕrloi′dēâ (N. L. *Perla*, a proper name + G. *eidos*, resemblance) 423
  A sub-class of *Pterygogenea*.
PERMIAN PERIOD (after Perm in eastern Russia) 397
PEROMEDUSAE, pē′rōmēdū′sē (G. *pera*, a pouch + L. *medusa*)..*256*, 419
PERONEAL ARTERY, perōnē′al (G. *perone*, pin of a brooch, referring to the fibula) 792
PERONEUS, perōnē′us (G. *perone*, fibula) 84
PERSONALITY, definition of....174
PES, pĕz (L. *pes*, foot)....45, 708
PETAL, pĕt′al (G. *petalon*, a petal).*242*
PETER 871
PETIOLE, pē′tēōl (L. *petiolus*, a little foot) *203*
PETRIFACTION, pĕtrĭfăk′shun (L. *petrosus*, stony + *facio*, to make), definition of 398
PETROGALE XANTHOPUS, petrog′âlē (G. *petra*, rock + *gale*, a weasel)..*657*
PETROHYOID, pĕtrohī′oid (G. *petros*, stone + *hyoides*, Y-shaped).... 81
PETROMYZON MARINUS, pĕtrō′mīzōn mârēnus (G. *petros* + *myzein*, suck) *641*
PETROMYZONTIA, pĕtrōmīzon′tia 424, 641
PETROSAL, petrow′sal (L. *petrosus*, rocky) 696
PEYER, pī′êr 380
PHAEOCHROME CELLS, fē′ōkrōm (G. *phaeos*, dusky + *chroma*, color), definition of 822
  Tissues, definition of....610
PHAGOCYTE, făg′ôsīt (G. *phagein*, to eat + *kytos*, hollow), definition of 199, 211
PHALANGES, faylan′gees (G. *phalanx*, battle-line) 76, 708
PHALAROPES, fālar′ōpēs (G. *phalaris*, a coot + *pous*, foot)....417
PHANEROCEPHALA, făn′erōsef′alâ (G. *phaneros*, visible + *kephale*, head) 420
PHANEROGAMS, fănĕr′ōgăms (G. *phaneros* + *gamos*, union)....225
PHANEROGLOSSA, făn′eroglôs′a (G. *phaneros* + L. *glossa*, tongue)....651
PHARYNGEAL POUCHES, definitions of 728
  Pockets 729
  Teeth 733
PHARYNX, fār′inks (G. *pharynx*, the throat) 267, 728
PHASCOLARCTUS, făskolark′tos (G. *phaskolos*, a leather bag + *arktos*, bear) 748
PHASES OF A CHEMICAL SYSTEM. 95
PHASMOIDEA, fasmoid′ēa (G. *phasma*, apparition + *eidos*, resemblance) 423
PHELLOGEN, fĕl′ojen (G. *phellos*, cork + *gene*, production)....231
PHENOMENA, MENTAL, fēnom′ĕnă (G. *phenomenon*, phenomenon)....173
PHILIDIUM, fĭlĭd′ĭŭm *308*

PHILODINA, filodĭ'na (new Latin word) *308*
PHILOSOPHY, filos'ofĭ (G. *philein*, to love; *sophia*, wisdom) 40
PHILTRUM, fĭl'trum (G. *philltron*, a love charm) 731
PHLOEM, flōĕm (G. *phloios*, smooth bark) 230
PHOLIDOTA, fōlidō'ta (G. *pholis*, scale) 426
The scaly ant-eater.
PHORONIDIA, for'onĭd'ēa..424, 432, 640
PHORONIS ARCHITECTA, forō'nis (G. *Phoroneus*, name of king of Argos) *309*
PHORONIS, forō'nis (G. *Phoroneus*).310
PHOTOPHORES, fō'tōfôrs (G. *phos*, light + *pherein*, to bear)..........668
PHOTOSYNTHESIS, fōtōsĭn'thĕsĭs (G. *phos*, light + *synthesis*, putting together), definition of..........128. 186
PHOTOTROPISM, fōtŏt'rōpĭzm (G. *phos* + *trope*, a turning), definition of 127
PHRENIC NERVE, fren'ik (G. *phren*, diaphragm) 755
PHYCOMYCETES, fīkomīsē'tez (G. *phykos*, sea-weed + *mykes*, *a* fungus) *207*, 208, 209
PHYLLAPHIA COWENI 169
PHYLLOXERA VASTATRIX, filoksē'ra (G. *phylon*, leaf + *xeros*, dry)..*350*
PHYLOGENY, fīlo'jenĭ (G. *phylon*, race + *genea*, birth).............. 31
PHYLUM, fye'lum (G. *phylon*, race, tribe) 415
PHYSALIA, fisā'lia (G. *physalis*, a bladder) 255
PHYSETER MACROCEPHALUS, fisē'ter (G. *physeter*, a blow-pipe).....*662*
PHYSICS 35
PHYSIOLOGICAL CONTINUITY....150
PHYSIOLOGUS, fĭsiŏl'ogus (G. *physis*, nature; *logos*, discourse) 377
PHYSIOLOGY, fĭzĭŏl'ôjĭ (G. *physis* + *logos*), definition of..............30, 31
PHYSOSTOMI, fīsŏs'tomi (G. *physa*, bladder + *stoma*, mouth).....761, 824
PIA MATER, pē'amâhtêr (L. *pia mater*, kind mother).............67, 838
PIGEON HORNTAIL, definition of...373
PIGEON SKELETON *703*
PIGMENT, pĭg'ment (L. *pingere*, to paint) 90
PIGMENT LAYER OF EYE.........579
Spots 46
PILIDIUM, pīlid'ium (G. *pilidion*, a small cap) 307
PINEAL EYE OF LIZARD, pin'eeal (L. *pinea*, pine cone).............. *46*
Gland or epiphysis......45, 490, *852*
PINUS INSIGNIS, pīnus ĭnsĭgnis (L. *pinus*, a fir + *insignis*, notable)...*231*
Silvestris, sĭlves'trĭs, pertaining to a forest 238, 240
PINUS STROBUS, pīnus (L. *pinus*, a pine tree) *240*
Virginiana *231*
PINWORMS, definition of 302
PIPA AMERICANA, pīpā amĕr'ikă'na.650
PISCES, piss'ees (L. fish)...242, 431, 641
PISIFORM BONE, pī'sĭform (L. *pisum*,.. pea; *forma*, shape)................703
PISTIL, pĭs'tĭl (L. *pistillum*, a pestle) *203*, 242
PITH, pĭth (A. S. *pitha*, pith), definition of *231*, 233
PITHECANTHROPUS ERECTUS, pithekan'thropus (G. *pithekos*, an ape + *anthropos*, man).......399, *400*
PITS, AUDITORY 480
PITTED TUBES, definition of.......234
PITUITARY BODY, pitu'itayree (L. *pituita*, mucus) 66, 490
PLACENTA, plasen'tă (L. *placenta*, cake) 626
Embryonic maternal 629
Foetal 631
Function of 627
PLACENTAL ANIMALS.........626, 658
PLACODES, AUDITORY, plăk'ōds (G. *plax*, a plate)................480, 574
PLACOID, plak'oid (G. *plax*, plate)..675
PLAGIOSTOMI, plājiŏs'tomī (G. *plagios*, oblique; *stoma*, mouth.)424, 642
PLANARIA, planār'ia (L. *planus*, flat) *286*
Maculata (L. *maculatus*, spotted).286
Polychroa 286
PLANKTON, plăngk'ton (G. *plangktos*, wandering) 325
PLANORBIS, plănor'bĭs (L. *planus*, flat + *orbis*, circle) 259
A mollusk.
PLANTARIS, plăntâr'is (L. *planta*, sole of the foot) 85
PLANT BODY 202
PLANT, FLOWERING *203*
Histology 228
Parts 202
Seed 203
PLANTIGRADE, plan'tigrade (L. *planta*, sole; *gradus*, walk)........713
PLANT WORLD—
Bryophytes 215
Flowers 242
Fungi 208
Histology 228
Pathogenic Fungi 209
Pollination 238
Pteridophytes 223
Simple plants 202
Spermatophytes 225
Thallophytes 204

  Three higher groupings 215
  Vaucheria 207
PLANULA, plăn′ūla (L. *planus*, flat) .254
PLASMA, BLOOD, plăs′ma (G. *plasma*, something formed), definition of... 62
PLASMODIUM IMMACULATUM LAVERANIA, plăzmō′dēum ĭmăkūlāt′um lăvêrān′ĭa (G. *plasma*, a moulded figure + *eidos*, form).....
  Malariae 130
  Vivax 133
PLASMOGAMY, plăsmog′ămy (G. *plasma*, a mould + *gamos*, marriage), definition of 147
PLASMOSOMES, plăs′mōsoms (G. *plasma* + *soma*, body), definition of. 91
PLASTIDS, plăs′tĭds (G. *plastos*, formed) 89, 92, *187*
PLASTIDULES, plăst′ĭdūls (G. *plastos*, formed [diminutive ending]) 91
PLASTOCHONDRIA, plăst′ōkon′drēă (G. *plastos* + *chondros*, cartilage). 91
PLASTOCONTS, plăs′toconts (G. *plastos*, formed) 91
PLASTOSOMES, plăst′ōsōms (G. *plastos* + *soma*).................... 91
PLASTRON, plăs′tron (F. *plastron*, a breast plate) *702*, *719*
PLATEMYS *683*
PLATO, plā′tō 376
PLATOPHRYS LUNATUS, plăt′ofris (G. *platys*, flat + *ophris*, brow)...*645*
PLATYHELMINTHES, plăt′yhĕlmin′thēz (G. *platys*, flat + *helmins*, a worm)..................265, 285, 427
PLATYHELMINTHES AND NEMATHELMINTHES, plat′ihelmin′thēz (G. *platys*, flat + *helmins*, a worm) 285, 311
  Flatworms 285
  Turbellaria 285
    Excretory system 286
    External appearance 286
    Muscular system 287
    Nervous system 287
    Regeneration 288
    Reproductive system 287
  Trematoda 289
    Infections by 291
    Life cycle of..................289
  Cestoda 293
    Eggs of *301*
    Infections by 295
    Life cycle of..................293
    Types of *296*
  Nematoda (threadworms).........298
    Ascaris 299
    Digestive system 300
    Eggs of *301*
    Excretory system 300
    Infections by 302
    Intermediate and Uncertain Forms 306
    Nervous system 300
    Parasitic *303*, 305
    Reproductive system 300
PLATYRRHINE, plăt′irĭn (G. *platys*, flat + *rhis*, nose) 659
PLATYSMA MYOIDES, plātĭs′ma (G. *platysma*, a flat piece)...........832
PLECOPTERA, plēkop′terâ (G. *plekein* twisted + *pteron*, wing)..........423
  An order of *Persoidea*.
PLECTOGNATHI, plektŏg′nathī (G. *plektos*, plaited + *gnathos*, jaw)...645
PLECTOPTERA, plĕktop′teră (G. *plekein* + *pteron*) 423
  An order of *Ephemeroidea*.
PLEROME, plĕr′ōm (G. *pleroma*, a filling up)..........................*228*
PLESIOSAURS, plē′siôsârs (G. *plesios*, near + *sauros*, lizard)...........651
PLEURA, plew′rah (G. *pleura*, rib, side) *315*
PLEURAL REGION 536
PLEURITES 336
PLEUROBRANCHS, plōr′ōbranks (G. *pleura*, a side + *brangchia*, gills)..321
PLEUROCOCCUS, plūrō′kôk′us (G. *pleura*; L. *coccus*, a berry)........*185*
PLEURODIRA, plorodī′ra (G. *pleura*, a side + *deire*, the neck).........652
PLEURODONT, plū′rōdōnt (G. *pleura* + *odontos*, a tooth).............733
PLEXUS, pleks′us (L. *interweaving*). 67
  Choroid, kōr′oid (G. *chorion*, skin + *eidos*, resemblance)....512, *571*
  Nerve 68
PLICA SEMILUNARIS, plik′āsĕmīlūnārĭs (L. *plica*, a fold + *semilunaris*, half-moon shaped) 875
PLICAE 46
  Fimbriatae (L. *fimbriatus*, fringed) 741
PLINY THE ELDER..................376
PLUMAE, plum′āy (L. *pluma*, a feather) 670
PLUMULAE, plew′miulee (L. little feather), definition of.............670
PNEUMATOPHORE, nūmăt′ōfor (G. *pneuma*, air + *pherein*, to hear)....*255*
PNEUMOGASTRIC, nūmōgas′trĭk (G. *pneuma* + L. *gaster*, stomach)..68, 885
PODICAL PLATE, pōd′ĭkl (L. *podex*, rump), definition of 337
PODIUM, pō′dēum (G. *pous*, foot), definition of 708
PODOBRANCHS, pō′dōbrănks (G. *pous* + *brangchia*, gills), definition of 321
PODOPHYRA, podo′fīră (G. *pous*, foot + *phyro*, to mix).............155

POECILOPODA, pēsilōp′odâ (G. *poekilos*, many-colored + *pous*, foot) .421, 429
POISON FANG 733
  Gland 46, *361*
POLAR BODIES, pōl′âr (G. *polas*, pivot), definition of 101, 444
POLARITY, definition of............288
POLAR NUCLEI, definition of.......244
  Spindle 444
POLE-CELLS, definition of..........259
POLLACK *583*
POLLEN, pŏl′len (L. *pollen*, fine flour) 226
  Sac, definition of................243
  Tube 239
POLLEX, pŏl′lĕks (L. *pollex*, thumb). 76, 710
POLLINATION (L. *Pollen*, fine flour), definition of 238
POLYCHAETA, pŏlĭkē′tâ (G. *polys*, many + *chaite*, mane)........283, 420
  A subclass of *Annelida*.
POLYCLADIDA, pŏliklăd′idâ (G. *polyclados*, many branched).......420
  An order of *Turbellaria*.
POLYDON SPATHULA *643*
POLYEMBRYONY, pŏl′iem′brĭōnĭ (G. *polys*, many + *embryon*, a fetus)..345
POLYGENETIC, pŏlĭjĕnĕ′tik), definition of 403
POLYGNOTUS, (G. *polys*, many + *notus*, known) 345
POLYGORDIUS, polĭgōr′dius (G. *polys*, many + *gordios*, gordius)...283
  Appendiculatus *280*
POLYMORPHIC, pŏlymor′fic (G. *polys*, many + *morphe*, form), definition of 255
POLYMORPHISM, pŏlimor′fĭzm (G. *polys* + *morphe*)................255
POLYP, pŏl′ip (L. *polypus*, a polyp)..251
POLYPEDE, pol′ypēd (G. *polys*, many + *pes*, foot), definition of.........310
POLYPHYLETIC, pŏlĭfĭlet′ik (G. *polys*, many + *phylon*, race), definition of.403
POLYPINUM *156*
POLYPLACOPHORA, poliplākof′orâ (G. *polys*, many + *plax*, a tablet)..421
  An order of *Amphineura*.
POLYPTERUS, polip′terus (G. *polys*, many; *pteron*, wing).........642, *643*
POLYSPERMY IN FOWLS, pŏl′ispêrmy 444
POLYTRICHUM COMMUNE, pŏl′ytrīkum cōmunāy (G. *polys*, many + *thrix*, hair) *217*
POND SCUM, definition of..........*204*
POND SNAIL 289
PONS, ponz (L. bridge) definition of. 512, 839, 859
PONS VAROLII, pŏns′ vārō′lēī (L. *pons Varolii*, bridge of Varolius)...*863*
PONTAL BRAIN FLEXURE, pŏn′tl (L. *pons*, a bridge)................837
POPLITEAL ARTERY, pop′litē′al (L. *poples*, the ham)..................792
PORCUPINE FISH *645*
PORES, EXCRETORY (G. *poros*)....266
PORIFERA, pōrif′erâ (G. *poros*, channel + L. *ferre*, to bear)...........427
POROSPORA GIGANTES, pōr′ōspōr′a jīgăn′tēs (G. *poros* + L. *sporum*, seed + *gigans*, large), definition of.153
PORTAL SYSTEM, pôr′tal (L. *porta*, gate) *50, 798*
PORTUGESE MAN-OF-WAR.........*255*
POST AXIAL, pōstak′sial (L. *post*, behind; *axis*, axle)................ 82
POST-ANAL GUT, pōst′ānâl (L. *post* + *anus*, vent)...................590
  Branchial bodies (G. *brangchia*, gills) 588,.744
  Caval, kāvl (L. *cavus*, hollow) ....
  Same as vena cava inferior.
  Optic commissure 858
  Otic, otik (G. *ous*, ear)..........739
  Trematic nerves, trēmăt′ĭk (G. *trema*, a hole)...................881
  Zygapophysis, zīgapŏf′ĭsĭs (G. *zygon*, yoke + *apo*, from + *physis*, growth) *73*
POUCHES, GILL, definition of.......498
  Visceral, vĭs′erăl (L. *viscus*, an internal organ), definition of....498
POULTON, PROFESSOR 385
PRACTICAL VS. THEORETICAL.... 22
PRAWN 325
PREAXIAL, prē′ăk′sēal (L. *prae*, before + *axis*, an axle)............ 82
PRECAVAL, prē′kā′vl (L. *prae* + *cavus*, hollow) ....
  Same as vena cava superior.
PRECHORDAL, prē′kōr′dl (L. *prae* + G. *chorde*, a cord)................474
PRECORACOID, prē′kōr′ăkoid (L. *prae* + G. *korax*, crow)................ 75
PREFORMATIONISTS, definition of.381
PREHALLUX, prē′hăl′uks (L. *prae* + *hallux*, the thumb)................ 46
PREHENSILE, prē′hĕn′sĭl (L. *praehendere*, to grasp).................659
PREMAXILLA, prē′măksĭl′la (L. *prae* + *maxilla*, jaw)...........48, 73
PREMOLAR TEETH, prē′mōl′r (L. *prae mola*, a hill)................*734*
PRE-ORAL GUT, prē′ōr′al (L. *prae* + *os*, mouth) 493
PRETREMATIC NERVES, prē′trēmat′ik (L. *prae* + G. *trema*, a hole).880
PREZYGAPOPHYSIS, prēzygăpŏf′ĭsĭs (G. *zygon*, yoke + *apo*, from + *physis*, growth) *73*
PRIAPULOIDEA, prīăp′uloid′ea (G. *priapos*, priapus + *eidos*, like).....311

PRIAPULPUS CAUDATUS 311
PRIESTLY, prēs′tlē 380
PRIMARY CORTEX, definition of....230
  Vesicles 478
  Tissues 228
PRIMATE, prī′mate (L. *primus*, first) 227, 426, 658
PRIMITIVE (L. *primus*, first)
  Groove, definition of..........455, 566
  Gut 457
  Pit 455
PRIMORDIAL, prīmōr′dēal (L. *primus*, first + *ordo*, order or rank).......100
PRINCIPLES VS. APPLICATIONS, ...25, 32
PROAMNION, prō′ăm′nēon (G. *pro*, before; *amnion*, a vessel for receiving blood), definition of 457
PROARTHROPODA, prō′ărthrŏp′ōda (G. *pro*, before; *arthros*, joint; *pous*, foot) 429
PROATLAS, prō′ătlâs (G. *pro* + Atlas, of Greek mythology), definition of..684
PROBABILITY OF ERROR CHART. 20
PROBOSCIDEA, prō′bŏsĭd′ēâ (G. *pro* + *boscein*, to graze)..........426, 662
PROBOSCIS, prō′bŏs′ĭs (G. *pro* + *boscein*) 285
PROCELLARIIFORMES, prō′selārēĭ-for′mēz (L. *procella*, a storm + *forma*, form) 425
PROCESS, TRANSVERSE (L. *procedere*, to go forth)............... 72
PRO-CHORDATE, prō′kōr′dāt (G. *pro* + *chorda*, a cord), definition of....638
PROCOELOUS, prō′sēlous (G. *pro*, before; *koilos*, hollow), definition of..683
PROCTODEUM, prok′tōdēum (G. *proctos*, anus; *daio*, divide), definition of 260
PROCTOTRYPID, proktotrĭp′ĭd (G. *proktos*, anus + *trypan*, to bore through) 345
PROGLOTTIDS, prō′glŏt′ĭds (G. *pro* + *glotta*, tongue), definition of....293
PROGONEATA, prōgōnēā′ta (G. *pro* + *gone*, a generative organ).......422
PROJECTION FIBERS (L. *proicere*, to throw forward, project), definition of 849
PROMORPHOLOGY, prō′mōrfŏl′oji (G. *pro* + *morphe*, form + *logos*, discourse) 31
PRONEPHRIC CAPSULE, prō′nef′rĭk (G. *pro* + *nephros*, kidney), definition of 606
  Chamber 606
  Duct 605
PRONEPHRIDIUM, prō′nēfrĭd′ium (G. *pro* + L. *nephredium*, a little kidney) 280
PRONEPHROS. prōnĕf′rŏs (G. *pro* + *nephros*) 504
PRO-NUCLEUS, pronuc′leus (G. *pro* *nucleus*, kernel), definition of..... ....102, 104, 150
  Otic (G. *ous*, ear).............72, 615
  Phase (G. *phasis*, appearance)...97, 98
PROPOLIS, prop′olis (G. *propolis*, substance with which bees line their hives), definition of..............365
PROSENCEPHALON, prōs′ĕnsĕf′ălon (G. *pro* + *en*, within + *kephalos*, head) 472
PROSENCHYMA, prōsĕng′kĭma (G. *pros*, near + *engchyma*, infusion) definition of 230
  Where found 233
PROSOCOELE, prō′sōsēl (G. *pros*, near + *koilos*, hollow), definition of....490
PROSTATE GLAND, pross′tayte (G. *prostates*, in the front rank)...282, 819
PROSTOMIUM, prō′stōm′ĭum (G. *pro*, before; *stoma*, mouth).............274
PROTECTIVE, definition of 178
  Tissues 234
PROTEIDAE, prōtē′ĭdē (G. *Proteus*, a sea-god + *eidos*, shape)...........649
PROTEINS, prō′tēnz (G. *protos*, first), definition of 96
PROTEROSPONGIA, prŏt′erospon′jĭa (G. *proteros*, fore + *spoggia*, a sponge) 151
PROTEUS ANGUINEUS, prōt′eus (G. *Proteus*, a sea-god)...............649
PROTHALLIUM, prō′thăl′ēum (G. *pro*, before + *thallos*, a young shoot), definition of 225
PROTHALLUS, prō′thăl′us (G. *pro* + *thallos*) *216*
PROTHORAX, prō′thōr′ăks (G. *pro*, before + *thorax*, breast)..........335
PROTOBRANCHIA, prō′tōbrănk′ia (G. *protos*, first + *brangchia*, gills).....421
PROTOCONE, prō′tōkōn (G. *protos*, first + *konos*, a cone), definition of.736
PROTOMERITE, prō′tōm′erit (G. *protos*, first + *meros*, part).........*151*
PROTONEMA, prō′tōnē′mă (G. *protos*, first + *nema*, thread).............220
PROTONEMATA, prō′tōnēmâ′ta (G. *protos* + *nema*) *219*
PROTOPLASM, prō′tōplazm (G. *protos*, first + *plasma*, form)........50, 89, 94
PROTOPODITE, prō′tŏp′ōdĭt (G. *protos*, first; *pous*, foot), definition of 314
PROTOPHYTES, PATHOGENIC, prō′-tōfīts (G. *protos*, *first; phyton*, plant) 210
PROTOPTERUS, prō′tŏp′tĕrus (G. *protos*, first; *pteron*, wing)........*646*

PROTOTHERIA, prō'tōthēr'ĭă (G. *protos*, first; *ther*, a wild beast) 424, 431, 656, *867*
PROTOTROPHIC, prō'tōtrō'phĭk (G. *protos*, first; *trophe*, nourishment), definition of 191
PROTOZOA, prōtōzō'ă (G. *protos*, first; *zoon*, animal)......121, 164, 426
Amoeba 121
Behavior of 126
Movement of 122
Euglena 127
Behavior of 129
Encystment 129
External features 127
Internal features 127
Locomotion 128
Nutrition 128
Reproduction 129
Flagellates of Uncertain Position...144
Paramoecium 138
Pathogenic Protozoa 142
Plasmodium Malariae 130
Life cycle *131*
How discovered 134
Summary of Protozoa.........147, 156
PROTRACTOR, prō'trăk'tŏr (L. *pro*, before; *tractus*, drawn out), definition of 739, 829
PROTURA, prōtu'ra (G. *protos*, first + *ura*, a tail)......................422
An order of *Mirientomata*.
PROVENTRICULUS, proh'ventrick'-yulus) (L. *pro*, before; *venter*, belly), definition of...........*276*, 745
PROVIVERRA, prōvĭve'ra...........*734*
PROXIMAL, prŏk'simal (L. *proximus*, nearest) 76
PSALTERIUM, sōltĕ'rium (L. *psalterium*, a psalter), definition of......745
PSEUDOBRANCHS, sū'dōbrănks (G. *pseudes*, false; *brangchia*, gills)....760
PSEUDOBRANCHUS STRIATUS, strīā'tus (L. *striatus*, striped).....650
PSEUDOPODIA, sū'dōpō'dia (G. *pseudes*, false; *pous*, foot), definition of 172, *215*, 219
PSEUDO-REDUCTION, definition of..102
PSEUDOTHYROID BODY, sū'dōthī'-roid, definition of.................588
PSYCHOLOGY, sīkŏl'oji (G. *psychos*, the soul + *logos*, discourse).....32, 40
Animal 172-184
Functional 175
Structural 175
PSYCHOZOIC, sīkōzō'ĭk (G. *psychus* + *zoon*, animal)..................*394*
PTERIDOPHYTES, tĕrĭd'ofīts (G. *pteris*, fern; *phyton*, plant)....203, 223
PTERIS, tĕris (G. *pteris*, fern)......*219*
PTEROBRANCHIATA, tĕro'brankiā'tā (G. *pteron*, wing + *brangchia*, gills) 424, 640
PTEROSAURS, tĕr'osōrs (G, *pteron*, wing + *saurus*, lizard)...........651
PTEROTIC, tero'tik (G. *pteron*, wing + *oys*, ear)......................696
PTERYGOGENEA, ter'ĭgōjē'nēâ (G. *pteryx*, wing; *genos*, kind)....423, 430
PTERYGOID, ter'igoid (G. *pteryx*, wing, *eidos*, resemblance)..72, 616, *692*
PTERYGOIDEUS MUSCLES, ter'-igoid'ēus (G. *pteryx* + *eidos*)......832
PTERYGOPODIAL GLANDS, ter'igō-pō'dēăl (G. *pteryx* + *pous*, foot)..668
PTERYGOQUADRATE, ter'igōquahd'-rāt (G. .*pteryx* + L. .*quadratus*, squared) 690
PTERYLA, tĕr'ila (G. *pteron*, feather; *yle*, a wood).......................*669*
PUBIS, pū'bis (L. *pubes*, mature).... 77
Homologue of 704
PUBOFEMORALIS, pūbōfĕmōrăl'ĭs ..829
PULEX IRRITANS, pew'lĕks ir'rĭ-tahns (L. *pulex*, a flea)...........*350*
Senaticeps *350*
PULMONARY CIRCULATION, pull'-mownay'ree (L. *pulmo*, lung)...... 54
PULMONATA, pulmōnā'tă (L. *pulmo*, lung) 421
PULSATING 93
PULVILLUS, pŭlvil'lus (L. *pulvillus*, a small cushion) 337
PUPA, pewpâ (L. *pupa*, a puppet)... ....332, 345, 363
PUPARIA, pewpā'rēa (L. *pupa*).....370
PUPIL, pewpil (L. *pupilla*, the pupil of the eye), definition of.......70, 874
PURPOSE OF FLOWER.............242
PURPOSITIVENESS 405
PUSILLA, pūsil'la (L. *pusillus*, very little, pretty) *149*
PYCONOGOMORPHA, pĭknogomor'fa (G. *pyknos*, thick + *gony*, the knee + *morphe*, form).................422
An order of *Pantopoda*.
PYGAL, pī'gal (G. *pyge*, rump)......*702*
PYLORIC CAECA, pīlōr'ik sē'ka (G. *pyloros*, a gate-keeper; L. *caecum*, blind) 747
PYLORIS, pīlōr'is (G. *pyloros*, a gate-keeper) 49, 318
PYLORUS, pyeloh'rus (G. *pyloros*, gate-keeper) *747*
PYORRHEA, pī'ōrē'ă (G. *pyon*, pus + *rhoia*, a flow)......................141
PYRAMIDAL, pyrăm'ĭdăl (L. *pyramis*, a pyramid) 320
PYRAMIDS (L. *pyramis*, a pyramid), in spinal cord, definition of........845
PYRENOIDS, pī'rĕnoids (G. *piren*, a fruit stone), definition of.....128, 204

PYRIFORMIS, pĭrĭfōr′mĭs (L. *pyrum*, pear; *forma*, shape) 83
QUADRANGULAR, quâdrăng′ulâr (L. *quadratus*, squared) 73
QUADRATOJUGAL, quâdrā′tōjūg′al (L. *quadratus* + *jugum*, yoke), where found 615
QUADRATUS, quadrâ′tŭs (L. *quadratus*) 84
QUARTAN FEVER, kwôr′tan (L. *quartanus* pertaining to the fourth) .132
QUILLWORTS, kwĭl′wôrts *224*
  A plant of the genus Isoetes with quill like leaves. One of the Fern Allies.
QUINCUNX, kwĭn′kŭngks (L. *quinque*, five + *uncia*, twelfth part), definition of 672
QUININA, kwīnē′na (L. *quinina*, quinine) *205*
  A species of *Spirogyra*.
RABBIT, rab′et (Fr. dial, *rabotte*, rabbit)—
  Brain of *863*
  Cross section of 832
  Dissection of *755*
  Muscles of *830*
  Skeleton of *702*
  Urogenital organs of 820
RADIAL CANALS, ray′deeal (L. *radius*, ray) 253
  Fibrovascular bundles 236
  Symmetry 247
RADIALE, ra′diā′lē (L. *radius*, ray) 76, 699
RADIATA 255
RADIATION 38, 851
RADICES AORTAE 786
RADIOLARIA 148, 418
RADIOULNA, rādiōul′nâ (L. *radius*, ray + *ulna*, elbow) 76
RADIUS, rā′diŭs (L. *radius*, ray) .*335*, *703*
RADIX, răd′iks or rā′diks (L. *radix*, root) 791
RAIA ERINACEA, rā′a (L. *raia*, a ray) *642*
RAINEY'S TUBULES, definition of .. *143*
RAMUS COMMUNICANS, ray′mus (L. a branch) *65*, 513
RANA ESCULENTA, rā′na (L. *rana*, frog) 51, *571*
  Fusca *551*
  Pipiens 43
  Sylvatica 583
RANA TEMPORARIA *549*
  Virescens *583*
RANIDAE, ran′idē (L. *rana*, frog + *idae*) 651
RANVIER, NODES OF 114
RAPHE, ray′fee (G. seam) 485
RAPHIDOIDEA 423
RASORES, rāsō′rēz (L. *rasor*, a scraper) 670
RATITAE, rātī′tē (L. *ratitus*, marked with the figure of a raft) 656
  Flightless birds.
RATHKE 380
RATHKE'S POCKET 490
RATTLESNAKE'S BITING MECHANISM *733*
RAY, JOHN 414
REASONING, definition of 182
REAUMUR 380
RECAPITULATION THEORY (same as Haeckel's Law of Biogenesis) ..
RECEPTACLE, rēsĕp′tăkl (L. *recipere*, to receive) *203*
RECEPTACULUM, rēsĕptăk′ūlum (L. *recipere*, to receive) 344
  Chyli 800
RECEPTOR, rēsep′tŏr (L. *recipere*, to receive) 177
  In immunity 198
RECESSIVE, rēsĕs′ĭv (L. *recessus*, withdrawn) 163
RECESSUS MAMMILLARIS *844*
  Opticus 512
RECTUM, rek′tum (L. *rectus*, straight) *48*, 338
RECTUS, rĕk′tus (L. straight) 79
RECURRENT NERVE, rēkur′ĕnt (L. *re*, back + *currere*, to run) 884
RED GLAND *761*
REDI, Italian scientist 382
REDIA, rēdiă (after Italian scientist, *Redi*) 290
REDUCTION DIVISION, rēduk′shun (L. *reductus*, reduced), definition of. 102
REDUCTION IN LIVER 51
REED, MAJOR WALTER 136
REESE 463, 500
REFLEX, rē′fleks (L. *reflectere*, to turn back), definition of 177
  Arcs *847*
  Centers 851
REFRACTION, rēfrăk′shun (L. *re*, back + *frangere*, to break) 39
REGENERATION, rējen′erā′shun (L. *re*, again + *generare*, to beget) 124
  In Hydra 251
REIL, ISLAND OF, definition of 843
REISSNER'S MEMBRANE *866*
REMORA BRACHYPTERA *645*
RENAISSANCE, Rĕnāsăns′ (L. *renascor*, to be born again) 377
RENAL COLLAR, ree′nal (L. *renes*, kidneys) *794*
  Portal system *798*
  Tubules *64*
REPRODUCTION, rē′prōduk′shun (L. *re* + *pro*, forth + *ducere*, to lead). 30
REPRODUCTIVE TISSUE *238*

REPTILE, rĕp'til (L. *repere*, to crawl)
  Brain of *862*
  Skull of *694*
  Medial eye of 45
REPTILIA, reptill'eeah (L. reptilus, reptile, from *repo*, creep) .425, 431, 651
RESIDUAL BODY, rēzid'ual (L. *residuum*, residue) *152*
RESISTANCE IN IMMUNITY, rēzis'tans (L. *resistere*, to resist) 196
RESONATOR, rez'onātor (L. *resonare*, resound) 63
RESPIRATION, res'pirā'shun (L. *re* + *spirare*, to breathe) 62
RESPIRATORY DUCT 870
RESTING STAGE (Ger. *rast*, repose). 98
RETE MIRABILE, ree'tee (L. intricate net) 761
RETICULAR LAYER, retik'ūlâr (L. same as Reticulate) 665
  Theory 95
RETICULATE TUBES, retik'ūlāt (L. *reticuluni*, a small net) 234
RETICULUM, rĕtik'ūlum (L. a small net) 85
  Of stomach 745
RETINA, ret'inah (L. *rete*, net)...70 ,873
RETRACTILE, rētrak'til (L. *retractus*,.. withdrawn) 740
RETRACTOR, rētrak'tôr (L. *retrahere*,.. to draw back) 739, 829
  Bulbi 828
  Muscles 257
RETROLINGUAL GLAND, ret'rôling'gwal (L. *retro*, backward + *lingua*, tongue) 742
REVEHENT, rēvē'hent or rev'ēhent (L. *revehens*, carrying back) 601
  Veins 799
REVERSION, rēver'shun (L. *re* + *vertere*, to turn) 675
RHABDITE, rab'dit (L. *rhabdos*, a rod) 286
RHABDOCOELIDA, rabdosē'lida (G. *rhabdos*, a rod + *koilos*, hollow)...420
RHABDOME, rab'dōm (G. *rhabdos*, a rod) *322*
RHABDOPLEURA, rabdoplu'ra (G. *rhabdos* + *pleuron*, a rib) *546*
RHABDURA, rabdu'ra (G. *rhabdos*, a rod) 422
RHACOPHORUS, rākof'orus (G. *rhakos*, a rag + *pherein*, to bear)..*650*
RHEIFORMES, rē'ifôr'mēz (G. *rea*, rhea + L. *forma*, form) 425
  Flightless terrestrial birds with partially feathered head and neck.
RHEOTROPISM, rēot'rôpizm (G. *rhein*, to flow + *trope*, a turning)..127
RHINENCEPHALON, rī'nensef'alon (G. *rhis*. nose + *engkephalon*, brain) 848
RHINOCEROTOIDEA, rīnŏs'erōtoi'dēâ (G. *rhinokeros*, nose, horned) 662
RHIZOIDS, rī'zoidz (G. *rhiza*, root + *eidos*, like) 208, 220
RHIZOMES, rī'zōmz (*rhizoma*, a root)223
RHIZOPODA, rīzop'ōdâ (G. *rhiza*, root + *pous*, foot)..142, 147, 418, 426
  Definition of 426
RHIZOPODS 122
RHODILES ROSAE, rōdī'lēz (G. *rhodites*, pertaining to a rose) *345*
RHODOPHYCEAE, rōdofī'sēē (G. *rhodon*, rose + *phykos*, sea-weed) 204
RHOMBENCEPHALON, rômb'ensef'alon (G. *rhombus*, magic wheel + *engkephalon*, brain) 472
RHOMBOID, rôm'boid (G. *rhombus* + *eidos*, like) 475, 677
RHOPALURA GIERDII, rōpal'ura (G. *rhopalon*, a club + *ura*) 307
RHYNCHOTA, ringkō'tô (G. *rhynchos*, snout) 424
  A subclass of *Pterygogenea*.
RIDGE, DENTAL 732
  Friction *678*
RIGHT, being right one-half one time, ... 19-26
RIZOPUS NIGRICANS *207*
ROCK WALLABY *657*
RODENTIA, rō'dĕn'shia (L. *rodens*, gnawing) 426, 658
RODS AND CONES *579*, 873
ROOT BRANCH, root (A. S. *wyrī*, root) *203*
  Cap 229
  Gall louse 350
  Stocks 223
  Tap *203*
ROSS, MAJOR RONALD 135
ROSTRUM, ross'trum (L. *rostrum*, beak) *313*
ROTARIES, rotar'ēs (L. *rota*, a wheel) .78
ROTATORIA 309
ROTATORS (same as rotaries) 78
ROTIFERA, rōtif'erâ (L. *rota*, wheel + *ferre*, to bear)....*308*, 424, 429, 432
  Definition of 432
RÜCKERT 466
RUDIMENT, rood'iment (L. *rudimentum*, first attempt) 45
RUDIMENTARY STRUCTURE..435, *436*
RUGAE, ru'jē (L. *ruga*, a wrinkle)..*739*
RUMEN, room'en (L. *rumen*, the throat) 745, *746*
  The first cavity of a ruminant's stomach.
RUMINANTIA, room'inantiâ (L. *rumen*, the throat) 661
SABAL, sā'bal (Said to be from a South American or Mexican name).*235*

SACCHAROMYCETES, sak′arōmīsēt′ez (N. L. *saccharum*, sugar + G. *mykes*, a mushroom), definition of ..210
SACCHAROMYCOSIS, sak′aromīkō′sis (G. *sakcharon* + N. L. *mycosis*, definition of 211
SACCULINA, definition of..........325
SACCULINA CARCINUS, sakūlī′nâ (L. *sacculus*, a little sack)........*327*
SACCULUS, sak′yulus (L. little sac.)867
SACCUS VASCULOSUS, sak′us (L. *saccus*, a sac) *844*
SAC-LIKE FUNGI..................207
SACRAL, say′cral (L. *sacer*, sacred), definition of 684
SAGGITA HEXAPTERA, saj′ita hexap′tera (L. *saggita*, arrow; G. *hexa*, six; *pteron*, wing) *308*
ST. AUGUSTINE 384
SAINT-HILARE 384
SALAMANDRA, salaman′drâ (L. *salamandra*, salamandria) ....
  Atra, ātra (L. black)...........649
  Maculosa, makūlōsa (L. spotted).649
SALAMANDRIDAE, definition of.....648
SALIVARY GLANDS, săl′ĭvăry (L. *saliva*, spit) 131
  Definition of 741, 742
SALIX, sā′liks (L. a willow); (species of willow) 203
SALMO FARIO, sal′mō (L. salmon).*644*
  The Brook Trout.
SALMON, sam′un (L. *salire*, to leap).644
SALPIANS, sal′pianz (N. L. *salpa*, a kind of stock fish), definition of....639
SALTATION THEORY, saltā′shon (L. *saltare*, to jump), definition of.....403
SALVIA, sal′via (L. sage)..........*366*
SALVINIA NATANS, salvin′ia (after Salvini, a Florence professor).....*224*
  A species of fern ally.
SALVINIALES (a Fern Ally).......*224*
SAMBONI, DR. 136
SANTORINI, DUCT OF (named after the Venetian anatomist, Santorini), definition of 751
SAPAJOU, sap′aju (F. *sapajou*, word of Tubi origin) *659*
SAPROLEGNIA, saproleg′nia (G. *sapros* + *legnon*, hem.)............*207*
SAPROPHYTE, sap′rofīt (G. *sapros*, rotten + *phyton*, plant), definition of 129, 208
SARCOCYSTIS, sarkōsis′tis (G. *sarcos*, flesh + *kystis*, bladder)...........153
  Lindemanni 153
  Miescheriana 143, 153
  Muris 153
SARCODE, sâr′kōd (G. *sarx*, flesh)...147
SARCOLEMMA, sar′kolem′a (G. *sarx*, flesh + *lemma*, skin), definition of.113
SARCOMERES, sâr′kōmē′rz (G. *sarx*, flesh + *meros*, part), definition of..114
SARCOPHAGA, sarkŏ′faga (G. *sarx*, flesh + *phagein*, to eat)...........*330*
SARCOPLASM, sâr′kôplasm (G. *sarx*, flesh + *plasma*, something moulded), definition of 113
SARCOPTES SCABEI, sarkop′tēz (G. *sarcos*, flesh + *koptein*, to cut)....*350*
SARCOSPORIDIA 143, 419
  Definition of 153
SARCOSTYLE, sâr′kŏstīl (G. *sarx*, flesh + *stylus*, pillar), definition of.113
SARSAPARILLA, sârsaparil′â (Basque *sarizia*, a bramble) *237*
SARTORIUS, sartoe′reeus (L. *sartor*, tailor) *80*
SAURIA, sô′ria (G. *sauros*, lizard), definition of *425*, 653
SAUROPSIDA, sahropp′sidah (G. *sauros*, lizard; *opsis*, appearance), definition of 638, 663
SAVIGNY'S LAW 313
SAW-FISHES, sâ fish′es (M. E. *saghe*, a saw) 642
SCALA MEDIA, skāla mēdia (L. *scala*, ladder + *medium*, middle).........866
  Definition of...................868
  Tyampani, definition of..........868
  Vestibuli, definition of..........868
SCALARIFORM TUBES, skala′rifôrm tūbs (L. *scala*, ladder + *forma*, form +*tubus* (water) pipe), definition of 234
SCALOPS AQUATICUS, skā′lops (G. *skalops*, a mole) *658*
SCAPHOGNATHITE, skafognâth′īt, skafog′nathīt (G. *skaphe*, boat + *gnathos*, jaw) *314*
SCAPHOID, skaf′oid (G. *skaphe*, boat + *eidos*, form) 709
SCAPHOPODA, skafo′poda (G. *skaphe*, boat + *pous*, foot) 421
  Definition of 429
SCAPULA, skap′yulah (L. shoulder blade) 75, 703
SCHISTOSOMUM JAPONICUM, skistō′sōmum (G. *schistos*, cloven + *soma*, body) *291*
  Haematobium *290*, *301*
  Japonicum vel Cattoi, definition of 291
  Japonicum *301*
  Mansoni *301*
SCHIZOCARDIUM BRAZILIENSE, skĭ′zōkâr′dium (G. *schizein*, to cleave + *kardia*, heart) *546*
SCHIZOMYCETES, skĭz′ōmīsē′tēz (G. *schizein* + *mykes*, fungus)....190, 210
SCHIZONTS, skĭz′ont′s (G. *schizein*, to cleave + *ons*, being), definition of..132
SCHLEIDEN 381

SCHLERENCHYMA (same as Sclerenchyma, which see).
SCHMIDT, INCISURES OF, definition of 114
SCHULL 418
SCHULTZE..........381, 386, 388
SCHWANN (see also Schleiden)..........381, 386, 388
SCIATIC ARTERY, sighat'ik (L. *sciaticus*, originally *ischiadicus*, from G. *ischion*, hip) 792
SCIENCE, sī'ens (L. *scientia*, knowledge), definitions of 25
Object of 26, 35
SCIENTISTS VS INVENTORS.......... 25
SCLERA, OF EYE, sklay'rah (G. *skleros*, hard) 872
SCLERENCHYMA, skelreng'kima (G. *skleros*, hard + *engchyma*, an infusion), definition of 234
SCLERITES, definition of..........336
SCLEROTIC BONES OF EYE, sklerot'ik (G. *skleros*, hard)..........875
Cells *235*
Coat 70, 687
SCLEROTOME, sklo'rohtome (G. *skleros*, hard: *tome*, cutting)..........*461*
SCOLEX, skō'leks (G. *skolex*, worm), definition of 293
SCORPIONES, skorpiō'nēz (G. *skorpios*, scorpion) 422
An order of *Arachnoidea*.
SCOURING RUSHES, skour'ing (M. L. *scurare*, to rub)..........*223*
SCREAMERS, skrē'mers (Sw. *skria*, cry aloud) 719
SCROTUM, scrō'tum (L. uncertain origin), definition of..........811
SCUTE, skiut (L. *scutum*, shield), definition of 676
SCYPHOZOA, sīfōzo'a (G. *skyphos*, a cup + *zoon*, animal)..........256, 419, 427
SEA ANEMONES *257*
SEA-COW *661*
SEA-HORSE *644*
SEA-SQUIRTS, definition of..........639
SEA-URCHIN, EGGS, EXPERIMENTS ON 206
SEBACEOUS GLANDS, sebā'shus (L. *sebum*, tallow), definition of..........673
SEBIFIC GLANDS, sebif'ik (L. *sebum*, tallow) 344
SECODONT, sek'odont (L. *secare*, to cut + G. *odous*, tooth)..........734
SECONDARY TISSUES, sek'ondari tī'shūs (L. *secondus*, second + F. *tissu*, woven) 231
SECRETION, sēkrēshun (L. *secernere*, to separate) 30, 63
SECRETION CAVITY, definition of...238
SECRETING CELLS 237
SECRETIONS.
Intestinal 52
SEED LEAF, sēd lēf (A. S. *saed*, seed + *leaf*, leaf)..........*203*
SEED PLANTS, sēd plănts (A. S. *saed*, seed + L. *planta*, plant), definition of 203
SEED SCALE, sēd skāl (seed + L. *scala*, ladder) 239
SEESSEL'S POCKET, definition of...493
SEGMENTAL APPARATUS, segmen'tal aparā'tus (L. *segmentum*, a segment + *apparatus*, an apparatus), definition of 848
SEGMENTAL DUCT, definition of..........605
Plate, definition of..........569
Zones, definition of..........458
SEGMENTATION, seg'mentāshun (L. *segmentum*, a segment)..........105, 106
Cavity, definition of..........448
SELACHII, sēlā'keī (G. *selachos*, a cartilaginous fish) 424
Definition of 642
SELECTIVE FACTOR, sēlĕktiv (L. *seligere*, to choose), definition of...404
SELENODONT, sēlē'nodont (G. *selene*, moon + *odous*, tooth)..........734
SELLA TURCICA, sel'a tūr'sika (L. *sella*, a seat + *turcicus*, Turkish; also called fossa hypophyseos) 687
SEMICIRCULAR CANALS, sem'iser'kūlar (L. *semi*, half + *circulus*, circle), definition of 867
SEMILUNAR GANGLION, sēmilū'nar gang'glion (L. *semi*, half + *luna*, moon). (See trigeminal ganglion)..884
SEMILUNAR VALVES, semm'iliu'nar (L. *semi*, half; *luna*, moon). definition of 541
SEMIMEMBRANOSUS, semimem'brano'sus (L. *semi*, half + *membranosus*, membranous) definition of. 83
SEMINAL RECEPTACLES, sĕm'ĭnăl (L. *semen*, seed)..........266
SEMINAL VESICLE 86.819
SEMINIFEROUS TUBULE, semm'iniff'erous (L. *semen*, seed; *fero*, to bear), definition of..........520
SEMITENDINOSUS sĕmitĕn'dinōsus (L. *semi*, half + *tendere*, to stretch), definition of 83
SENNA, sen'a (Hind. *sena*, a name)..*234*
SENSORY MEMORY, sen'sōri mem'ōri (L. *sensus*, sense + *memoria*, memory), definition of 178
SENSU STRICTO 423
SEPAL, sē'pal (G. *sepalon*, a sepal)..*242*
SEPTA, sep'ta (L. *septum*, partition), definition of 266

SEPTIBRANCHIA, sep′tibrang′kia (L. *septum*, partition + G. *brangchia*, gills) 421
  An order of *Pelecypoda*.
SEPTIC, definition of 192
SEPTUM, sepp′tum (L. fence, wall)
  Interbranchial 758
  Oblique 756
  Pellucidum *842*
  Transversum, definition of....756
SERIAL HOMOLOGY, sē′rial (F. *seriel*, serial) 316
SEROSA IN INSECTA, seerow′sah (L. *serum*, serum), definition of....346
SEROUS GLANDS, se′rus gland (L. *serum*, serum + *glans*, an acorn), definition of 742
SERRANUS, sera′nus (L. *serra*, a saw) 824
SERRATUS, sērā′tŭs (L. *serra*, saw), ...80, 829
SERTOLI ....
  Foot or sustentacular cells of.520, 811
  (See also testes.)
SERUM, sē′rum (L. *serum*, serum).. 62
SESAMOID BONES, sess′amoid (G. *sesamon*, a plant, referring to the shape of the seeds)....828
SESSILE, ses′il (L. *sedere*, to sit)...205
SETAE, sē′tē (L. *seta*, bristle) *259*, 283
SEVERINUS 379
SEX-LINKAGE, seks ling′kaj (L. *sexus*, sex + *lingula*, a small tongue from *ligare* to bind), definition of...168
SEXUAL REPRODUCTION, sek′sūal rēprōduk′shun, in *Vaucheria* (L. *sexus*, sex + *re*, again + *producere*, to bring forth) 207
SEYMOURIA 694
SHANK, shangk (A. S. *scanca*, bone of leg), definition of....45, 84, 708
SHARK-SUCKER *645*
SHELL-GLANDS, shel glands (A. S. *schell*, shell + L. *glans*, an acorn).816
SHOCK, ANAPHYLACTIC, definition of, see anaphylactic....201
SHORT-HORNED GRASSHOPPER...*352*
SHREW, shru (A. S. *screwa*, a wicked person, a shrew-mouse)....*658*
SIEVE TUBES, siv (A. S. *sife*), definition of 230, 235
SIGMOID FLEXURE, sig′moid flekshur (G. E. *sigma* + *eidos*, *shape*, + L. *flexus*, the bending)....748
SILICA, si′lika (L. *silex*, flint).... 93
SILUROIDS, silu′roids (G. *silouros*, a river fish)....761
SIMIA SATYRUS, sim′ia (L. *simia*, an ape) *660*
SIMPLEX UTERUS, sim′pleks (L. *simplex*, simple), definition of....819
SINUS, sigh′nus (L. *sinus*, curve)....284
  Rhomboid, definition of....475
  Terminalis, definition of....467
  Venosus *55*, 58, 501
SINUSOID, sīn′ūsoid (L. *sinus*, curve + *eidos*, shape) 795
SIPHONOGLYPHAE, sifonoglif′ē (G. *siphon*, tube + *glyphein*, to engrave) 256
SIPHONOPHORA *255*, 419
SIPHUNCULATA, sīfungkūlā′tă (L. *siphunculus*, a small tube)....423
  An order of *Pterygogenea*.
SIPHUNCULOIDEA, sifunkūloid′ia (L. *siphunculus*, a small tube + G. *eidos*, shape), definition of....311
SIPHUNCULUS NUDUS, sifun′kūlus nūdus (L. *siphunculus*, a small tube + *nudus*, naked) *311*
SIREN LACERTINA *649*
SIRENIA, sīrē′nia (L. *siren*, a siren or mermaid) 426
  Herbivorous, educabilian, placental mammals, having the body fishlike in form with the hind limbs and pelvis more or less atrophied, and the body ending in a horizontal expansive tail.
  Definition of 662
SIRENIDAE 650
SKATES, skāts (probably L. *squatus*, a kind of shark)....*641*, 642
SKEINS, skāns (Ir. Gael. *sgain*, split) 99
SKELETOGENOUS SHEATH, skell′etoj′eenous (G. *skeleton*, from *skello*, make dry) 612
SKELETON, INTERNAL, skel′eton (G. *skeletos*, dried, hard).... 46
SKULL, skŭl (M. E. *skulle*, the cranium) 73
SKULL—
  Development of 539
  Of reptile *692*
  Representative types of....*694*
SLOTH, slŏth (A. S. *slāw*, slow)....*659*
SNAKES, snāks (A. S. *snaca*, creeper).651
  Definition of 654
  Skull of *692*
SOCIOLOGY, sōsīŏl′ōji (L. *socius*, companion + G. *logos*, discourse)... 32
SOL 148
SOLAR PLEXUS, soh′lar (L. *sol*, the sun; *plexus*, interweaving), definition of 878
SOLIFUGAE, sōlif′ūjē (L. *sol*, sun + *fugere*, to flee)....422
  An order of *Lipoctena*.
SOMATIC LAYER, sohmat′ik (G. *soma*, body), definition of....259

SOMATOBLASTS, sōm′atoblasts (G. *soma*, body + *blastos*, bud), definition of 281
SOMATOPLASM, sōm′atoplasm (G. *soma*, body + *plasma*, something moulded), definition of 99
SOMATOPLEURE, soh′matoeplure (G. *soma*, body; *pleura*, side), definition of 259
SOMITE, soh′might (G. *soma*, body), definition of 264
    Metameric, definition of..........460
SOREX VULGARIS, sor′eks (G. *hyrax*, a shrew-mouse)..........*658*
SORI, definition of..........224
SORUS, sō′rŭs (G. *soros*, a pile).....*225*
SOUL, sōl (Goth. *saiwala*, soul), definition of 174
SPALLANZANI 206, 380
SPECIES, spē′shiēz (L. *species*, a particular kind) 164
    Definition of 402
    Origin of new..........403
SPECIFIC, spĕsif′ik (L. *species*, a particular kind + *facere*, to make), definition of 95
SPELERPES FUSCUS, spēler′pēz fus′kus (G. *spelaion*, a cave + *herpein*, creep) 738
SPERM, spĕrm (G. *sperma*, seed) 85
SPERMARIES, spĕr′maries (G. *sperma*) 86
    Of *Hydra* *248*
SPERMATHECA, sper′mathē′ka (G. *sperma*, seed + *theke*, a case)......*151*
    Of insect, definition of..........*361*
SPERMATIC, spermat′ik (G. *sperma*, sperm).
    Artery 793
SPERMATOCYTES, spĕr′matōsīts (G. *sperma*, seed + *kytos*, hollow), definition of 100
SPERMATOGONIA, spĕr′matogō′nia (G. *sperma*, seed + *gonos*, offspring), definition of 100
SPERMATOPHORES, spĕr′matōfōrs (G. *sperma*, seed + *pherein*, to bear) 276
    Definition of 344, 825
SPERMATOPHYTES, sper′matōfītēz (G. *sperma* + *phyton*, plant), definition of 203 225
SPERMATOZOA, spĕr′matōzō′a (G. *sperma* + *zoon*, animal), definition of 101
SPERM-SAC 218
SPHAEROPHYRA, sfērof′ira (G. *sphaira*, a ball + *phyro*, to mingle).155
SPHAGNALES, sfăgnā′lēz (G. *sphagnos*, a kind of moss), definition of..215
SPHARGIS CORIACEA, sfar′jis kor′lasēa 652
SPHENETHMOID, spĕnĕth′moid (G. *sphen*, wedge + *ethmos*, sieve + *eidos*, form) *72*
SPHENISCIFORMES, sfēnis′kifôrm′ēz (G. *spheniskos*, a wedge + L. *forma*) 425
    Penguins. Flightless marine birds with small, scale-like feathers; wings modified as paddles for swimming; one family.
SPHENODON PUNCTATUM, sfee′nohdon (G. *sphen*, wedge; *odous*, tooth).*651*
SPHENOID, sfee′noid (G. *sphen*, wedge) 692
SPHINCTER MUSCLES, sfing′kter (G. *sphinggein*, to bind tightly)........763
    Definition of 828
SPIDERWORT, spīderwĕrt (name of plant) *229*
SPINAL CORD, spī′năl kôrd (L. *spina*, + G. *chorde*, a cord).......... 67
    Cord, cross section of..........877
SPINAL NERVES, spī′nal nĕrvs (L. *spina*, spine + *nervus*, sinew)...... 67
SPINA SCAPULAE, spē′na skăpūlē (L. *spina*, spine + *scapula*, shoulder-blade) 704
SPINDLES, spĭn′dls (A. S. *spinnan*, to spin) 99
SPINE, spīn (L. *spina*, spine)....67, 681
SPINE, DORSAL, spīn′ dōr′sal (L. *spina*, spine + *dorsum*, back)...... 74
SPIRACLE, spear′ahkel (or spire′ahkel) (L. *spiraculum*, air hole), definition of 329
    Of fishes 766
    Of insect ear..........*336*
    Of tadpole 549
SPIRACULUM, spĭ′răk′ūlŭm (L. *spiraculum*, an airhole), definition of.729
SPIRAL TUBES, spī′ral tūbs (L. *spira*, a coil + *tubus*, a pipe), definition of 234
SPIRAL VALVES, spī′ral vălvs (L. *spira*, a coil + *valva*, a fold), definition of 754
SPIREME STAGE, spī′rēm (G. *speirema*, a coil)..........*97*, 99
    Definition of 98
SPIRILLUM, spīrĭl′um (L. *spirillum*, a small coil), definition of........190
SPIRITUALIST, spĭ′rĭtūalĭst (L. *spiritualis*, spiritual), definition of....174
SPIROCHAETA RECURRENTIS, definition of *146*
    Refringens *146*
SPIROCHAETE DENTIUM, spīrōkē′ta (G. *speira*, a coil + *chaite*, a bristle) *146*
    Plicatilis *146*
SPIROGYRA, spīrojī′ra (G. *speira* + *gyros*, a circle), definition of.......*204*

SPIROSTOMUM, spīros'tomum (G. *speira* + *stoma*, mouth) 154
SPLANCHNOLOGY, splăngknŏl'ôjĭ (G. *splanchnon*, an entrail + *logos*, a discourse) 31
SPLANCHNOPLEURE, splank'nohplure (G. *splanchnon* + *pleura*, side), definition of 259
SPLEEN, splēn (G. *splen*, spleen) . *48*, 53
Development of 604
SPLENIAL, splee'neeal (G. *splen*, spleen) 697
SPONGIOPLASM, spŏn'jioplasm (L. *spongia*, a sponge + G. *plasma*, something moulded), definition of . . 90
SPOONBILL *643*
SPORANGIA, spôrăn'jĭa (G. *sporos*, seed + *anggeion*, vessel), definition of 243
SPORANGIOPHORES, sporăn'jiofōrs (G. *sporos*, seed + *anggeion*, vessel + *pherein*, bear), definition of 209
SPORANGIUM, spōrăn'jiŭm (G. *sporos*, seed + *anggeion*, vessel), definition of 209
SPORE-CAPSULE, spōr-kăp'sŭl (G. *sporos*, seed + L. *capsula*, capsel) . . 218
SPORE-CASE, spōr-kās (G. *sporos*, seed + L. *capsa*, chest, box), definition of 209, 219
SPORE-MOTHER-CELL (archeospore) 243
SPORE-MOTHER CELLS 219
SPOROBLASTS, spō'rôblăsts (G. *sporos*, seed + *blastos*, bud) 152
Definition of 132
SPOROCYST, spō'rosist (G. *sporos*, seed + *kystis*, bladder), definition of 290
SPOROGENESIS, spō'rōjĕ'nesis (G. *sporos*, seed + *genos*, offspring) *131*
SPOROGENOUS, spōrŏj'enŭs (see Sporogenesis), definition of 219
SPOROPHYTE, spō'rofīt (G. *sporos*, seed + *phyton*, plant) 215
Definition of 219
SPOROTRICHOSES, sporotrīkō'sēs (G. *sporos* + *thrix*, hair), definition of) . 213
SPOROTRICHUM, *Beurmanni* *213*
SPOROZOA, spō'rozō'a (G. *sporos*, seed + *zoon*, animal) 143, 419
Definition of 151, 427
SPOROZOITES, spō'rozō'īts (see Sporozoa), definition of 132
SPORT IN NATURE 164
SPORULATION, spôr'ūlāshŭn (L. *sporula*, a small seed), definition of . 126
SQUALUS ACANTHIAS, skwā'lŭs a'kanthi'as (L. *squalus*, a kind of sea-fish) *642*
SQUAMATA, skwammay'tah (L. *squama*, scale) 425
SQUAMOSAL, skwâmō'sāl (L. *squama*, scale) 72, 74
SQUAMOSALS 618
SQUAMOUS, skwā'mŭs (L. *squama*, scale), definition of 109
SQUARROSUM, skwărō'sŭm (L. *squarrosus*, scurfy). (Species of Sphagnum) *216*
STAMENS, stā'mens (L. *stare*, to stand) *203*, *242*
STAPES, stay'peez (L. stirrup) . 716, *867*
STAPHYLOCOCCUS, staf'īlokok'us (G. *staphyle*, a bunch of grapes + *kokkos*, a berry), definition of 191
STARCH, startch (Ger. *starke*, starch) 50
STATOCYST, stătosĭst (G. *statos*, stationery + *kystis*, bladder) 255, 323
STAUROMEDUSAE, stâromēdūsē (G. *stauros*, a cross + L. *Medusa*, feminine name) *256*, 419
STEAPSIN, stēăp'sĭn (G. *stear*, tallow + *pepsis*, digestion) 50, 268
STEGOCEPHALA, steg'ohseff'ahlah (G. *stego*, cover; *kephale*, head) 425, 646, *694*
STEMONITIS, stēmonī'tis (G. *stemon*, warp in loom, a thread + *itis*, inflammation) 205
STENOBOTHRUS, stenoboth'rus (G. *stenos*, narrow + *bothros*, a hole) . . *339*
STENOPS, sten'ops (G. *stenos*, narrow + *opsis*, to look) 741
STENSON 380
Duct of 742
Gland of, definition 872
STENTOR, sten'tor (G. *Stentor*, a Greek hero in the Trojan War), definition of 154
STERIGMATA, stĕrig'mata (G. *sterigma*, a support) *207*
STERILIZATION, stĕrĭlĭzā'shŭn (L. *sterilis*, barren), method of 191
STERILIZING, stĕrīlī'zing (L. *sterilis*, barren) 38
STERNAL, stĕr'nal (G. *sternon*, breast) 319
STERNEBRA, stir'nebrah (G. *sternon* + L. *vertebra*, joint) *701*
STERNITES, stĕr'nīts (G. *sternon*, breast), definition of 336
STERNOCLEIDOMASTOID, stĕr'nō (G. *sternon*, breast-plate + *kleis*, key + *mastos*, mastoid + *eidos*, resemblance) 829
Also Sternomastoid.
STERNOHYOID, sternohī'oid (G. *sternon* + *hyoides*, Y-shaped) 81
STERNOTHAERUS NIGRICANS, sternothē'rus (G. *sternon* + *thairos*, hinge of a door) *719*
STERNUM, stir'numm (G. *sternon*, breastbone), definition of *315*

STIGMA, stĭg′ma (G. *stigma*, a pricked mark) *127*, 242
  Of insect ear *336*
STIGMATA, stĭg′mătă (plural of stigma), definition of 334
STIMULATION, stĭ′mūlā′shŭn (L. *stimulare*, to incite) 52
STIMULI, stĭ′mūlī (plural of stimulus) 30
STIMULUS, stĭ′mūlūs (L. *stimulare*, to incite) 77
STING, OF BEE, stĭng (A. S. *stingan*, to sting) *361*
STIPES, stī′pĕz (L. *stipes*, stalk), definition of 335
STIPPLE IMAGE, stip′l (Ger. *stippen*, to prick), definition of....................321
STOLONIFERA, stō′lŏnĭf′era (L. *stolo*, a shoot + *ferre*, to carry)....................420
  Definition of 256
STOMA, stō′ma (G. *stoma*, mouth)...*220*
STOMACH, stŭ′măk (G. *stomachos*, throat, gullet) *48*
STOMATA, stō′mâtâ (G. *stoma*, mouth) 222
STOMODEUM, stow′mohdeeum (G. *stoma*, mouth; *daio*, divide), definition of 260
STOMOXYS CALCITRANS, stomok′sis kal′sitrans (G. *stoma* + *oxys*, sharp) 369
STORAGE TISSUES, stor′aj (L. *staurum*, to store) 237
STRATIFIED, stră′tĭfīd (L. *stratum*, layer + *facere*, to make), definition of 109
STRATUM, stray′tum (L. a spread or cover) 665
STREAMING MOVEMENT 139
STREAMING OF PROTOPLASM.....552
STREAM OF CONSCIOUSNESS, strēm (Ger. *strom*, a stream), definition of 174
STREPSIPTERA, strēpsĭp′terâ (G. *strephein*, twist + *pteron*, wing)...423
  An order of *Coleopteroidea*.
STREPTOCOCCUS, streptōkok′us (G. *streptos*, twisted + *kokkos*, a berry).190
STREPTONEURA, streptonu′ra (G. *strephein*, twist + *pteron*, wing)...423
STREPTOTHRIX ACTINOMYCES, strepto-thriks(G. *streptos* + *thrix*, hair) *214*
  Israeli *214*
  Madurae 214
STRIATED, strīā′ted (L. *stria*, a channel) 77
STROBILIZATION, strō′bilīzā′shŭn (G. *strobilos*, a fir cone)..........293
STRONGYLOIDES INTESTINALIS, stronjĭloi′dēz (G. *strongylus*, globular + *eidos*, resemblance)..........306
  Stercoralis *303*
STRUCTURE DETERMINES FUNCTION, strŭk′tsher (L. *struere*, to build) 176
STRUCTURE, EXTERNAL, struk′tsher 44
  Internal 46
STRUGGLE FOR EXISTENCE.......403
STRUTHIONIFORMES, strŭthion′ifôrmez (L. *struthio*, ostrich + *forma*, form) 425
  The ostrich. Flightless, terrestrial, two-toed birds.
STURGEONS, ster′jons (F. *esturgeon*, a sturgeon) 642, *643*
STYLE, stīl (L. *stilus*, a pricker)....*244*
STYLO-HYAL, stī′lō-hī′ăl (G. *stylos*, column + *hyoides*, Y-shaped)......738
STYLOID PROCESS, stīl′oid (G. *stylos*, pillar + *eidos*, resemblance), definition of 738
STYLONICHIA 154
STYLORHYNCHUS *151*
SUBARACHNOID, sŭbarăk′noid (L. *sub*, under; G. *arachne*, spider; *eidos*, resemblance) 838
SUBARTICULAR PADS 46
SUBCEPHALIC POCKET, definition of 464
SUBDURAL, sŭbdū′ral (L. *sub*, under; *durus*, hard) 838
SUBGENITAL PLATE, sŭbje′nĭtal (L. *sub*, under + *genitalis*, genital)....337
SUBINTESTINAL VEINS, sŭbĭntes′tĭ′nal (L. *sub*, under + *intestinus*, internal) 794
SUBJECTIVE, sŭbjek′tĭv (L. *subiicere*, to throw under), definition of......173
SUBLINGUA, sŭblĭn′guă (L. *sub*, under + *lingua*, tongue)....................741
SUBMANDIBULAR GLAND, sŭbmăndĭb′ūlar (L. *sub*, under + *mandibula*, a jaw) 742
SUBMENTUM, sŭbmen′tŭm (L. *sub*, under + *mentum*, chin), definition of 335
SUBMUCOSA, sŭbmūkō′sa (L. *sub*, under + *mucosus*, mucous)........ 49
SUBSTANTIA ALBA, sŭbstăn′sĭâ âl′bâ (L. *substantia*, substance + *alba*, white), definition of 847
  Grisea, definition of 847
  Propria 514
SUBTHALAMUS, sŭbthă′lamŭs (L. *sub*, under + G. *thalamos*, bridal chamber), definition of....................851
SUBUMBRELLA, sŭbŭmbrel′la (L. *sub*, under + It. *ombrella*, from *ombra*, shade), definition of.......254

SUBUNGUIS, sŭbŭng'gwĭs (L. *sub*, under + *unguis*, nail), definition of .667
SUBZONAL LAYER, sŭbzō'nal (L. *sub*, under + *zona*, belt) definition of 621
SUCKERS, OF TADPOLE, sŭk'ers (A. S. *sucan*, to suck) 548
SUCTORIA, sŭktō'rĭa (L. *sugere*, to suck), definition of ..153, 155, 419, 424
SUCTORIAL, sŭktō'rial (see Suctoria) 739
SUCTORIAL PADS 254
SUGAR, shŭ'gar 50
SUIDAE, sū'idē (L. *sus*, swine + *idae*, like), definition of 660
SUINA, sūī'na (L. *sus*, swine), definition of 661
SULCI, sŭl'si (L. *sulcus*, furrow) ....
  Of brain 843
  Lateral limiting, definition of 486
SULCUS, sull'kuss (L. a furrow or groove) 730
SULZE (jelly) *632*
SUPERPOSITION IMAGE, sū'perposi'shŭn (L. *super*, above; *ponere*, to place) 322
SUPPORTING TISSUE, sūpōr'ting (L. *supportare*, to bring up to), definition of 234
SUPPORTING TISSUE CELLS OF VERTEBRATES 462
SUPRAOCCIPITAL, sū'prăŏksĭp'ital (L. *supra*, above + *occiput*, back part of head) 73
SUPRAORBITAL LINE, sū'prâor'bĭtal (L. *supra*, above + *orbis*, a circle) .582
SUPRA-PERICARDIAL BODIES, sūprâpĕrĭkar'dial (L. *supra*, above + G. *peri*, around + G. *kardia*, heart), definition of 588
SUPRA-RENAL, sūprâ-rē'nal (L. *supra*, above + *renes*, kidneys), definition of 822
  (See also *adrenal*, *epinephric*.)
SUPRAROSTRAL CARTILAGES, sūprârŏs'tral (L. *supra*, above + *rostrum*, beak) 613
SUPRASEGMENTAL APPARATUS, sūprâsegmen'tal (L. *supra*, above + *segmentum*, segment), definition of .848
SUPRATEMPORAL LINE, sūprâtem'pōral (L. *supra*, above + *tempus*, time) 584
SURANAL, sūrānal (L. *supra*, above + *anus*, anus), definition of 336
SURANGULARE, sūrăng'ulârĕ (L. *supra*, above + *angulus*, an angle) .*692*
SURANIM TOAD, surī'nam (South American name) 650
SURFACE TENSION THEORY, sŭr'fes ten'shun (L. *super*, upon + *facies*, face), definition of 122
SURVIVAL OF THE FITTEST 403
SURVIVAL VALUE, servī'val (L. *super*, over + *vivere*, to live), definition of 403
SUSPENSORIUM, sūspensōr'ĭūm (L. *suspendere*, to hang down), definition of 74
SUTURE, sū'tūr (L. *suo*, to sew) 336
SUTURES, sū'tūrz (L. *sutura*, a seam, in insects), definition of 336
SWAMMERDAM 379
SWAN, CIRCULATION IN, swân (Ger. *schwan*) *785*
SWEAT GLANDS, swĕt (A. S. *swat*), definition of 672
  In amphibia 63
SWIMMERET, swim'eret (Dim. of *swimmer*) *313*
SYLVIUS, JACOBUS 378
SYLVIUS 380
  Aqueduct of, definition of ...511, 845
  Fissure of 843
SYMBIOSIS, sĭmbiō'sĭs (G. *symbioun*, to live together) 208
SYMBRANCHII, simbrang'kiī (G. *syn* + *brangchia*) 643
SYMPATHETIC CHAIN, sĭmpăthĕt'ik (G. *syn*, with + *pathos*, feeling) *65*
  Ganglion *65*
  Ganglia 514
  Nervous system *578*
  Of insect *359*
  Nervous system, definition of 66
SYMPHOPLEONA, simfōplē'ōna (G. *symphorein*, to bear together + *pleion*, more) 422
  An order of *Collembola*.
SYMPHYLA, sĭm'fĭlâ (G. *syn* + *phylon*, tribe) 422
  An order of *Progoneata*.
SYMPHYSIS, simm'feesis (G. union) 77, 697
SYNAPSIS, sinăp'sĭs (G. *synapsis*, union), definition of 101
SYNCYTIUM, sĭnsit'ium (G. *syn*. with + *kytos*, hollow), definition of .114, 207
SYNERGID, sĭnĕr'jĭd (G. *synergos*, cooperating), definition of 244
SYNOTIC TECTUM, synot'ik (G. *syn*, Together, *ous*, ear), definition of 687
SYNSACRUM, sĭnsā'krŭm (G. *syn*, with + L. *sacrum*, holy) 706
SYNTHESIS TISSUES, sĭn'thesis (G. *syn*, with + *thesis*, a setting, an arrangement), definition of 236
SYPHILIS, sif'ilis (N. L. *syphilis*, from poem "*Syphilus*") 146, 147
SYRINX, sir'inks (G. pipe), definition of *764*
SYRPHUS FLIES, sĕr'fus (G. *syrphos*, a gnat) *368*
SYSTEMATIC ARCH *55*

SYSTEMATISTS, sis'tematists (G. *systema*, an arrangement)..........379
SYSTEMIC ARCH 531
Circulation 33
SYSTOLE, sĭs'tōlē (G. *systole*, a drawing together) 56

TABANUS, tabā'nŭs (L. *tabanus*, a gad fly) *330*
TABLE OF ANIMALS..........418, 432
TACHINA FLY, takī'nâ (G. *tachus*, swift) *368*
TACTILE, tăk'tĭl (L. *tangere*, to touch) 254
TADPOLE, tăd'pol (M. E. *tade*, toad + *polle*, head) 547
Eggs and adult stage of frog..... *44*
TAENIA CONFUSA, tē'nĭa konfū'sa (L. *taenia*, ribbon) 298
Cucumerina 297
Same as *dipyl dium caninum.*
Echinococcus 295
Elliptica 297
Flavo-punctata 297
Mediocanellata 295
Multilocularis 297
Nana 298
Saginata 295
Solium 293
TALON, tă'lon (L. *talus*, ankle).....*736*
TALUS, tā'lus (L. *talus*, ankle).....709
TAMANDUA TETRADACTYLE, tămăn'dūâ (native name for four-toed *ant-bear*) *659*
TAMANIX GALLICA 349
TAPEWORMS *294*
TAPIRIDAE, tāpir'idē (native name).662
Family of tapirs.
TAP ROOT, tap'root (M. E. *tappe*, a short pipe + A. S. *wyrt*, root).....203
TARDIGRADA, tärdig'rādâ (L. *tardigradus*, slow-going) 429
TARENTOLA, taren'tōlâ (native name) *655*
Mauritanica—
A genus of *Geckones.*
TARPON, tar'pon (native name) *644*
TARSAL, tar'sal (G. *tarsos*, a flat surface) 77
Glands 673
TARSUS, târ'sus (G. *tarsos*, sole of the foot) 328, 708
TASTE BUDS 741
TAXIS, tăk'sis (G. *taxis*, arrangement), definition of 126
TAXONOMY, tăksŏn'ômi (G. *taxis*, arrangement + *nomos*, law)......... 32
TECTUM SYNOTICUM, tek'tum (L. *tego*, to cover)...............*539*, 687
TEETH ALVEOLI, tēth (A. S. *toth*, a tooth), definition of 733
Classification of 732, 737
Development of 731
Egg 737
Of fishes 731
Names according to usage and shape 733
Pharyngeal 733
TEGMEN CRANII, tĕg'men 687
TEGMENTUM, tegmen'tum (L. *tego*, to cover) 840
TEGMINA, tĕg'mina (L. *tegmen*, covering) 336
TELAE CHOROIDEAE, tē'lē 860
TELEOSTEI, tell'eeos'tee'eye (G. *teleos*, whole, perfect, *osteon*, bone) 425, 643
TELEOSTOMI, tell'eeoss'toemy (G. *teleos*, perfect, *stoma*, mouth)..425, 642
TELOCOELE, tĕ'losēl 511
The vesicle in the *Telencephalon.*
TELOLECITHAL, tell'ohless'ithal (G. *telos*, end, *lekithos*, yolk)..........550
TELOPHASE, tĕl'ofāz (G. *telos*, end + *phasis*, aspect)...............*97*, 98
TELOSPORIDIA, telōspōrid'ea (G. *telos*, end + *spora*, seed).143, 152, 419
Sporozoa in which the life of the individual ends with spore formation.
TELSON, tĕl'son (G. *telson*, extremity) *313*
The unpaired terminal abdominal segment of *Crustaceans.*
TEMNOSPONDYLOUS, tĕm'nôspon'dĭlŭs (G. *temnein*, to cut; *sphondylos*, a vertebra)..................*682*
With vertebrae not fused, but in articulated pieces.
TEMPORAL, tem'pohral (L. *tempus*, temple) 697, 843
Pertaining to, or in the region of the temples.
TEMPORALIS, tempôral'is (L. *tempus*, time) 81
TENACULUM, tĕnăk'ūlŭm (L. *tenax*, holding) 875
In *teleosts*, a fibrous band extending from eyeball to skull.
TENDON, ten'don (L. *tendo*, to stretch) 78
A white, glistening, fibrous cord connecting a muscle with a movable structure.
TENSOR, tĕn'sôr (L. *tensus*, stretch).*336*
TENTACLES, tĕn'tăklz (L. L. *tentaculum*, a feeler) 247
Slender flexible organs on the head of many small animals, used for feeling, exploration, etc., as in snails, insects, crabs.
TENTACULOCYSTS, tĕntăk'ūlosists (L. L. *tentaculum*, a feeler + G. *kystis*, a bladder)..................256
Club-shaped bodies on the umbrella margin.

TENTORIUM, tentoh'reeum (L. *tendo*, to stretch) 838

TERATOLOGY, tĕr'atŏl'ōjĭ (G. *teras*, a monster + *logos*, discourse) 31

TERES, tee'reez (L. round) *155*
  Ligament 797

TERGITE, tēr'jīt (L. *tergum*, back) . 336
  The dorsal chitinous plate on each segment of most *Arthropoda*.

TERGUM, tĕr'gum (L. *tergum*, back) . 315

TERRESTRIAL VERTEBRATES, tĕrĕs'triăl (L. *terra*, earth) 663
  Vertebrates living on the ground as opposed to aerial, aquatic.

TERTIAN FEVER, tĕr'shân (L. *tertianus*, of the third day), definition of 132

TESSERA PRINCEPS, tĕs'êrâ (G. *tessarec*, four) 256

TESTES, tess'teez (L. *testis*) 47, *48*
  Paired male reproductive organs producing spermatozoa.
  Descent of *818*

TESTUDINIDAE, testūdin'idē (N. L. *testudo*, tortoise) 652

TESTUDO ELEPHANTOPUS 720
  Ibera *719*

TETRABRANCHIA, tetrabrang'kia (G. *tetra*, four + *branchia*, gills) 421
  Cephalopods with four gills, four kidneys, and four auricles, and large external shell, no suckers, and short arms. Example—*Nautilus*.

TETRAD, tĕt'rad (G. *tetras*, four) ... 102
  A group of four.

TETRAPODA, tetrap'ōda (G. *tetra*, four + *pous*, foot) 663

TETRAXONIDA, tetrakson'idâ (G. *tetra* + *axon*, axis) 419
  Sponges with tetraxon spicules.

TETRONERYTHRIN, tet'ronerith'rin (G. *tetra* + *on* + *erythros*, red) .. 318

TETROPHIS 222
  A species of worms.

THALAMENCEPHALON, thal'ămĕnsef'ălŏn (G. *thalamos*, a receptacle; *engkephalon*, the brain) 66

THALAMUS, thal'amus (L. chamber) 571, 839, 849

THALASSICOLA, thălasikol'ă (G. *thalassa*, the sea + *kolla*, glue) 148
  The typical genus of *Thalassacolidae*.

THALESSA, thăles'ă *372*
  (Native name, subgenus of *purpora*.)

THALIACEA, thăliă'sēâ (G. *thaliea*, blooming) 424, 639
  Free swimming *Urochordata* without tail in adult.
  Example—*Salpians*.

THALLOPHYTE, thal'lofīt (G. *thallos*, a young shoot + *phytos*, a plant) 203, 204

THALLUS, thăl'ŭs (G. *thallos*, a young shoot) 220

THECODONT, thee'kohdont (G. *theke*, sheath; *odous*, tooth), definition of . 733

THECOPHORA, thēkŏ'fōra (G. *theke*, sheath; *pherein*, to bear) 652

THEOPHRASTUS, thēōfrăs'tus (*Theophrastus*, a Greek philosopher) 376

THEORETICAL VS. PRACTICAL ... 22

THEORIES OF LIFE 157

THE PLANT-WORLD .. 185, 193, 202, 246

THERAPEUTICS, therapū'tiks (G. *therapon*, an attendant) 197

THERMOMETERS 38

THERMOTROPISM, thĕrmŏt'trôpizm (G. *therme*, heat + *trope*, a turning) 127

THEROMORPHOUS, thērōmôr'fus (G. *ther*, a wild beast + *morphe*, form) 45, 77

THIGMOTROPISM, thĭgmot'rôpizm (G. *thigma*, touch + *trope*, a turning) 126

THORACIC, thohras'ik (L. *thorax*, thorax) 319, 364
  Duct 800

THOUGHT, definition of 182

THREADWORMS 285, 302

THYMUS, thy'mus (G. *thymon*, thyme) 53, *743*
  Development of 587
  Extracts of 52

THYROHYALS, thĭrôhīalz (G. *thyra*, door + *hyoeides*, Y-shaped) 738
  The greater cornua of the hyoid bone.

THYROID (or THYREOID), thy'roid, thy'reeoid (G. *thyreos*, shield) .. 53, *743*
  Cartilages 763
  Development of 588
  Extracts of 52

THYSANOPTERA, thisanop'terâ (G. *thyranos*, a tassel + *pteron*, wing) . 423
  Insects with four narrow, membranous wings fringed with long hairs as the *Thrips*.

THYSANURA 422, 430

TIBIA, tibb'eeah (L. *tibia*, the shin bone) 77, *703*

TIBIALIS, tĭbĭăl'ĭs (L. *tibia*, the shin bone) *80*

TIBIO-FIBULA, tĭb'iofib'ūla (L. *tibia*, a flute + *fibula*, which see) *76*

TICKS, definition of 373

TISSUE, tis'u or tish'ū (F. *tissu*, woven) 46
  Absorption 234
  Assimilating 236
  Botryoidal 284
  Conducting 234
  Covering 234

Fundamental 229
Mechanical 234
Primary 228
Protective 234
Reproductive *238*
Secondary 231
Storage 237
Supporting 234
Synthesis 236
TOLERANCE 196
TONGUE, tŭng (A. S. *tunge*, tongue).
Development of 588
Extensile 47
TONSIL, ton'sil (L. *tonsilla*, tonsil) 731, *739*
TOOTH OF RATTLESNAKE *733*
TOPOGRAPHICAL, tŏpōgrăf'ikal (G. *tophos*, place + *graphein*, write) ... 464
TORPEDOES 642
TORRENS 388
TORSION, tôr'shun (L. *torquere*, to twist) 480
The twisting round of a gastropod body as it develops.
TORUS TRANSVERSUS, tō'rus (L. *torus*, a swelling) 571
TOXIC, tŏx'ik (G. *toxikon*, poison) ... 95
TRABECULAE ,trabek'yulee (L. little beam) 56
Carnae 530, 541
Cranii 540
TRACHEAE, trākēē (G. *trachys*, rough) *495*
TRACHEATA, trākēāt'a (G. *trachys*, rough) 312
TRACHEIDS, trăk'ĕīds (L. *trachia*, windpipe) *231*, 235
TRACHYMEDUSAE, trak'imēdū'se (G. *trachys*, rough + L. *medusa*, medusae) 419
Hydrozoa without alternation of generations.
TRÄGER *623*
TRAINING, MEANING OF 32, 157
TRANSITIONAL CELLS, trănzĭsh'ŏnăl (L. *transire*, to go across) 557
TRANSVERSE PROCESS, trănz'vers (L. *trans*, across + *vertere*, to turn) .72
TRAPEZIUS, trapee'zeeus (G. *trapeza*, table) 829
TRAPEZOID, tra'pezoid (G. *trapeza*, table) 709
TREMATODA, trematō'dâ (G. *trema*, a pore + *eidos*, resemblance) 285, 420, 427
The liver flukes.
TREMEX COLUMBA, trē'meks (G. *trema*, a hole) 373
TREPONEMA PALLIDUM, trēpōnē'ma (G. *trepein*, turn + *nema*, thread) .*146*
The spirochete of syphilis.
TRIAL AND ERROR 140, 181
TRICEPS, try'seps (L. *tres*, three; *caput*, head) 81
TRICHIA, trĭk'ia (G. *thrix*, hair) ... 205
TRICHINA, trikī'nă (G. *thrix*, a hair) 302
A parasite nematode worm.
TRICHINELLA SPIRALIS, trĭkĭnĕl'la. *299*
TRICHINIASIS (see *trichina*) 302
TRICHOCEPHALUS DISPAR, trĭkosĕf'alus (G. *thrix*, a hair + *kephale*, the head) *305*
TRICHOCYSTS, trĭk'ôsists (G. *trix*, hair + *kystis*, bladder) 138
TRICHOMONAS, trĭkŏm'ōnas (G. *thrix*, hair + *monos*, single) *145*
TRICHOPTERA, trĭkop'tera (G. *thrix*, hair + *pteron*, wing) 423
Insects with four membraneous wings, longitudinally veined and covered with hairs. Example—*Caddice Flies*.
TRICHOSTRONGYLUS ORIENTALIS *301*
TRICHURIS TRICHIURA, trĭkūr'is trĭkū'ra (G. *thrix*, a hair + *oura*, tail) *301*
A genus of Trematoda.
TRICLADIDA 420
Turbellaria with three main branches to intestine.
TRICONODONT, trīcōn'odont (L. *tres*, three + *conus*, a cone + *G. odontos*, a tooth) *736*
TRICUSPID VALVES, trykus'pid (L. *tres*, three; *cuspis*, point) 804
TRIFID NUCLEUS, trī'fid (L. *tres*, three + *findere*, to cleave) 118
TRIGEMINAL GANGLION, trījĕm'ĭnal (L. *trigeminus*) 575
TRIGEMINUS, tryjem'inus (L. three at a birth, triple) 68
TRIGODONT, trīgōdont (L. *tres* + *odontos*, a tooth) *736*
TRIGONUM LEMNISCI, trīgō'num (L. *trigonum*, a triangle) 839, 841
TRIONYX GANGETICUS, trī'oniks (L. *tres*, three + *onyx*, a nail) *683*
TRIONYX HURUM (see above) (L. *tres* + G. *onyx*) *683*
TRIPLOBLAST, trip'lôblăst (G. *triplax*, triple + *blastos*, a bud) .107, 247
TRIQUETRUM, trĭkwet'rum (L. *triquetrus*, three-cornered) 709
The cuneiform carpal bone; a wormian bone.
TRIRADIAL, trīrā'diăl (L. *tres*, three; *radius*, a ray) 678
TRITICUM, trit'icum (L. *triticum*, wheat) 233
A genus of grasses.
TRITON CRISTATUS, trī'ton cristā'tus (G. *Triton*, a sea god) 584, *648*

TROCHANTER, trohkan'ter (G. *trochos*, wheel) 328, *701*, 711
TROCHLEARIS, trŏk'lēâr'is (G. *trochilia*, a pulley) 68
TROCHOPHORE, trôk'ôfōr (G. *trochos*, wheel + *pherein*, to bear) 309
TROCHOSPHERE, trôk'ôsfēr (G. *trochos*, wheel + *sphaira*, globe) . . .280
TROPHECTODERM 629
TROPHOBLAST, trŏf'ôblast (G. *trophe*, nourishment + *blastos*, bud) .622
TROPHODERM, trof'ôderm (G. *trophe*, nourishment + *derma*, skin) 625, 629
TROPICAL BOIL 144
TROPISM, trō'pizm (G. *trope*, a turning) 126
TRUNCATELLA, trunk'atel'la (L. *truncare*, cut off) *155*
TRUNCUS ARTERIOSUS, trunk'us artēr'iō'sus (L. *truncus*, a stock) *54*, *55*, 58, 595
TRYPANOSOMA GAMBIENSE, trĭpăn'osō'mah (G. *trypanos*, borer + *soma*, body) 143
TRYPSIN, trĭp'sĭn (G. *tryein*, to rub down + *pepsis*, a digestion) 50, 268
TSCHERMAK 388
TSETSE FLY 144, *369*
TUBE FUNGI, tūb (L. *tuba*, a pipe) .208
TUBER CINERUM, tiu'bur (L. a swelling) 852
TUBERCLES, tū'bĕrkl (L. *tuberculum*, a small hump) *192*
TUBERCULA PUPERTATIS 277
TUBERCULUM POSTERIUS, tiuburr' kiulum (L. *tuberculum*, a little swelling) 512, 570
  Impar *739*
TUBEROSITIES OF TEETH........*735*
TUBES—
  Annular 234
  Latex 235
  Pitted 234
  Reticulate 234
  Scalariform 234
  Sieve 235
  Spiral 234
TUBIFEX, tūb'ifĕks (L. *tubus* + *facere*, to make) 283
  A sub-class of *Oligochaeta*.
TUBIPORA MUSICA, tūbĭ'pera (L. *tubus*, a tube + *pora*, a pore) 256
  Pipe-organ coral.
TUBO-TYMPANIC CAVITY 586
TUBULIDENTATA, tū'būlidentā'tă (G. *tubulus*, a tube + *dentatus*, toothed) 420
  Burrowing mammals of Africa known as Cape ant-eaters.
TUNIC, tū'nik (L. *tunica*, a coating) .752
TUNICA OF EYE (See *tunicata*) .872, 873
TUNICATA, tiu'nikay'tah (L. *tunica*, tunic) 424, 430, *543*, 639
  Fixed forms of *Urochordata* without tail in adult. Example—sea squirt.
TURBELLARIA, terbelā'riâ (L. *turbo*, disturb) 285, 420, 427
  Free-living *Platyhelminthes* with ciliated ectoderm.
TURBINAL, turr'binal (L. *turbo*, anything that whirls) *868*
TURBINATE, tŭr'bināt (L. *turbo*, a whirl) 696
TURTLE 651
  Skull of *692*
  Urogenital system of...........*825*
TYMPANIC, TYMPANUM, timpan'ik, tim'panum (L. *tympanum*, drum) .45, 71
TYMPANOHYAL, tim'pănohīăl (G. *tympanon*, a drum + *hyoeides*, Y-shaped) 738
TYMPANUM, tĭm'pănŭm (G. *tympanon*, a drum) 71
  Of bird trachea.................764
  Of Insect *336*
TYPES OF *CESTODA*, tīp (L. *typus*, an image) *296*
TYPHLOMOLGE RATHBUNI, tiflōmol'jē (N. L. A genus of tailed amphibia) 650
TYPHLOPIDE, tiflŏp'ĭdē (N. L. *typhlops* + G. *eidos*) 417
TYPHLOSOLE, tĭf'lôsōl (G. *typhlos*, blind + *solen*, a channel) *259*
TYSON 379

ULNA, ull'nah (L. *ulna*, elbow)......*703*
ULNARE, ŭlnā'rē, or ulnarā (L. *ulna*, elbow) 76
ULTIMOBRANCHIAL BODIES, definition of 588
UMBILICAL GROOVE OF FEATHER, umbilical, umbill'ikel (L. *umbilicus*, navel) 671
UMBILICUS, ŭmbĭlī'cus (L. navel) . .632
UNCINARIASIS 303
UNCINATE PROCESS, unn'seenate (L. *uncus*, hook) 719
UNCINATUS GYRUS *844*
UNDULATING MEMBRANE, definition of 139
UNEQUAL SEGMENTATION, definition of 106
UNGUES, definition of 337
UNGUICULATA, unggwikulă'tâ (L. *unguiculus*, a nail) 426, 658
  Clawed Mammals.
UNGUIS, ŭng'wis (L. *unguis*, claw), definition of 667
UNGULATA, ung'gūlā'ta (L. *ungula*, hoof) 426, 660
  Mammals with hoofs.

UNGULIGRADE, unngiu'ligrade (L. *ungula*, hoof; *gradus*, walk), definition of 714
UNIRAMOUS 315
UNISERIAL, ū'nisē'rial (L. *unus*, one + *series*, rank), definition of..........707
UNIT, biological 88
  Characters 165
URACHUS, ū'răkus (G. *ouron*, urine + *echein*, to hold)..........629
URCEOLATA, ŭr'sēōlā'tâ (L. *urceolus*, small pitcher) *148*
UREA, ūrē'a (G. *ouron*, urine).......... 64
URETER, yuree'ter (G. *ouron*, urine) 64, 85, 518, 810
URETHRA, yuree'thrah (G. *ouron*, urine) ....
  The canal from the bladder through which urine is discharged.
URIC ACID 339
URINIFEROUS TUBULES *64*
URINOMETERS 38
URNATELLA 310
UROCHORDATA, ŭrôkôrdā'ta (G. *oura*, tail + *chorde*, cord) .424, 430, 639
  The group of pro-vertebrates in which the notochord is confined to the caudal region.
UROCYST, ū'rôsist (G. *ouron*, urine + *kystis*, a hollow), definition of...810
URODELA, yu'rowdee'lah (G. *oura*, tail; *delos*, evident)..........425, 647
  Amphibians with persistent tails.
UROGENITAL PLEXUS, ūrōjĕn'ital (G. *ouron*, urine; L. *genitalis*, genital) 68
  Sinus 629, 824
  Systems *812*, *815*
UROGLENA 150
UROHYAL, ūrôhī'al (G. *oura*, tail + *hyoeides*, Y-shaped), definition of..740
UROPATAGIUM, ū'rôpatā'jium (G. *oura*, tail + *patagium*, border)....*329*
UROPODS, ū'rôpods (G. *oura*, tail + *pous*, foot), definition of..........314
UROPYGIAL GLAND, ūrōpij'ĭal (G. *oura*, tail; *pyge*, rump)..........670
UROSTYLE, yu'rowstyle (G. *oura*, tail; *stylos*, column)..........67, 72
URSUS ARCTUS, ŭr'sŭs ârktus (L. *ursus*, a bear) *734*
UTERUS, yu'terus (L. *uterus*, womb) *86*, 818
  Masculinus 819
UTRICULUS, yutrik'yulus (L. a little bag) *866*, 867

VACUOLES, vak'ūōlz (L. *vacuus*, empty), definition of 89
VAGINA, vajye'nah (L. a sheath)....
VAGUS, vay'gus (L. wandering)..... 68
  Ganglion 65
VALVE, vălv (L. *valva*, fold)..........
  Auriculo-ventricular *55*
  Bicuspid, definition of..........786
  Mitral, definition of..........786
  Spiral *55*
  Spiral, definition of..........754
VALVES—
  Of heart, how formed..........778
  Semilunar *55*
  Sinu-auricular *55*
  Tricuspid 804
VALVULA CEREBELLI, văl'vūlă (L. *valvula*, a small fold)..........*857*
VAN HELMONT 380, 381
VAN LEEUWENHOEK 378
VARANUS 787
  Salvator 654
VARIATIONS, vā'riā'shunz (L. *variare*, to change)..........164, 402
VAROLII, PONS *863*
VASA EFFERENTIA, vă'sâ ĕffĕrĕn'shēă (L. *vas*, a vessel; *ex*, from + *ferre*, to carry), definition of..........610
  Vasorum 781
VASCULARIZATION 629
VASCULAR SYSTEM, vas'kūlar (L. *vasculum*, a small vessel)..........223
VAS DEFERENS (L. *vas* + *deferre*, to carry from), definition of..........610
VASTUS, vass'tus (L. vast).......... *80*
VAUCHERIA *187*, 207
VEGETABLE POLE, definition of....105
VEIN, vān (L. *vena*, vein)..........53, 60
  Abdominal *61*
  Ant. abdominal *54*
  Artery and nerve *58*
  Brachial *61*
  Dorso-lumbar *61*
  Femoral *48*, *61*
  Hepatic *61*
  Hepatic portal *54*, *61*
  Iliac *61*
  Musculocutaneous *54*, *61*
  Ovarian 61
  Pelvic 48, *61*
  Postcaval 54, *61*
  Precaval 54, *61*
  Pulmo-cutaneous *54*
  Pulmonary *54*, *55*, *61*
  Renal *61*
  Renal portal *48*, *54*, *61*
  Sciatic *61*
  Sinus venosus *54*
  Spermatic 61
  Transverse iliac *61*
  Vesical *48*, *61*
VELUM, vee'lum (L. veil), definition of 254
  Anterior medullary, definition of.859
  Of *Hydra* *251*
  Medullare, definition of..........841
  Palati, definition of..........730
  Transversum, definition of...512, 856

VENA CAVA, vē'na ca'va (L. *vena* + *cava*, hollow), definition of........775
VENTER, vĕn'tĕr (L. *venter*, belly), definition of *218*
VENTILATION 38
VENTRAL, vĕn'trăl (L. *venter*, belly). 47
VENTRICLE, vĕn'treekel (L. *venter*, belly) ....
  Laryngeal, definition of..........764
  Of heart, definition of......479, 778
VENTRICLES—
  Of brain, where located......840-841
  Lateral, definition of.............511
VENTRICULUS, ventrik'ūlŭs (L. *ventriculus*, dim. of *venter*, belly), definition of 329
  Impar *571*
VENULES, ven'ūlz (L. *venula*, dim. of *vena*, vein) ....
VERMIN *350*
VERMIS, vĕr'mĭs (L. worm), definition of 859
VERTEBRAL PLATE, ver'tĕbrăl (L. *vertebra*, joint), definition of......461
VERTEBRATA, verretebray'tah (L. *vertebra*, joint)................424, 431
  Definition of 640
VERTEBRATE, ver'tebrāte (L. *vertebra*, joint) 43
VERTEX, vĕr'teks (L. *vertex*, top)..*335*
  Breech measurement *633*
VESALIUS 378, 386, 388
VESICAL, vess'ikal (L. *vesica*, bladder) ....
  Allantoic, definition of..........488
  Blastodermic (see blastoderm).
  Germinal, definition of...........443
  Of nucleus 551
  Seminal *86*
VESICLES, vĕs'ikls (L. *vesicula*, a vesicle) 93
VESICULA SEMINALIS, sĕm'inăl'is (L. *vesicula* + *seminalis*, pertaining to seed; by usage, sperm).......... *48*
VESTIBULE, ves'tĭbūl (L. *vestibulum*, passage) *820*
  Of ear 866
  Of ear, definition of.............868
  Of nose, definition of............871
VESTIGIAL, vestij'ĭal (L. *vestigium*, trace) 316, 574
VICQ D' AZYR........................380
VILLI, vĭlī (L. *villus*, shaggy hair)..627
  Definition of 725
VINEGAR EEL 306
VIRCHOW 389
VIRULENCE, vir'ūlĕns (L. *virulentus*, full of poison) 199
VISCERA, viss'errah (L. *viscus*, internal organ) 47
VISCERAL ARCHES, vis'ĕral (L. *viscus*, internal organ)............. 74
  Definition of 585
VISCERAL CLEFTS—
  Definition of 498, 686
  Muscles, definition of...........826
  Pouches, definition of 498
  Skeleton 73
  Skull, definition of..............538
VITALISM, vī'talizm (L. *vita*, life)..405
VITALLY SECRETORY GLANDS, definition of 673
VITELLINE ARTERIES, vī (or vĭ) tell'inn (L. *vitellus*, yolk).........471
  Glands *292*
VITELLINE (pertaining to yolk)...438
VITELLINE VS. OMPHALOMESENTERIC, definition of 483
VITELLUM, definition of............438
VITELLUS, vĭtĕl'us (L. *vitellus*, yolk) 438
VITREOUS HUMOR, vit'reeous (L. glassy) *579*
  Definition of 70
  Of eye 873
VIVERRA, vīver'ra (L. *viverra*, a ferret) *734*
VIVERRA INDICA, teeth of.........735
VIVIPAROUS, vĭvĭp'ârŭs (L. *vivus*, alive + *parere*, to beget)...........619
VOCAL CORDS, vō'kâl (L. *vox*, voice) 43
  How formed 762
VOICE BOX *763*
VOLANT, vō'lant (L. *volans*, flying).654
VOLAR, vō'lăr (L. *vola*, palm of hand) 69
VOLVOCACEAE, vŏl'vōkā'sēē (L. *volvere*, to turn around)..........*207*
VOLVOX, vŏl'vŏks (L. *volvere*)......129
  Definition of 150
  Globator *207*
VOMER, voh'mer (L. ploughshare).48, 73
VOMERO-NASAL ORGAN (L. *vomer*), definition of 872
VOMERS, vomers (L. *vomer*).......617
VON BAER 382, 386, 388
VORTEX, vôr'teks (L. *vortex*, vortex).522
VORTICELLA, vōrticĕl'la (L. *vortex*, a whirl), definition of.............155

WALDHEIMIA AUSTRALIS........*311*
WALLACE, ALFRED RUSSELL.385, 406
WARBLE FLY 348
WAX GLANDS, wăks (A. S. *weax*, wax) 364
WEBER 380
WEIGHT OF HUMAN EMBRYO....632
WEISMANN, AUGUST 161, 384
WEISMANNIAN BRIDGE 162
WHALEBONE 737
WHALES 662
WHARTON'S DUCT, definition of....742
  Jelly 632
WHAT TO OBSERVE 28
WHEELER 418
WHIPWORM 306
WHITE MATTER 67, 836

WHORLS, hworlz (A. S. *hweorfa*, a wheel) *242*
WHY TO STUDY.................... 19
WIDAL REACTION, definition of....200
WILDER 744, 748
WILLIS, CIRCLE OF, definition of..792
WING MUSCLES OF INSECT, wĭng (M. E. *winge*, wing)..............*340*
WING OF INSECT.................*335*
WINSLOW, FORAMEN OF, definition of 746
WINTHEMIA 4-PUSTULATA........*368*
WIRSUNG'S DUCT, definition of....751
WISHBONE 704
WÖHLER 380
WOLFF 381, 386, 388
WOLFFIAN BODY, wolf'eean (after K. F. Wolff, German anatomist), definition of 482, 504, 808
  Duct *64*
  Ridge 510
WOOD, wŏod (A. S. *wudu*, wood), definition of 230
WUNDT, WM. 182

X-CHROMOSOME, definition of.*100*, 168
XENOPUS 650
XIPHISTERNUM, zifistĕr'num (G. *xiphos*, sword + L. *sternum*, breast) 701
XIPHOID, zif'oid (G. *xiphos*, sword + *eidos*, shape)...............*80*, *701*
XIPHOSURA, zif'ōsūra (G. *xiphos*, sword + *oura*, tail)...............421
  King-crabs.

Y-CHROMOSOME, definition of......168
YEASTS 211
YELLOW FEVER—
  How caused 136
YOLK PLUG, yōk (A. S. *geoloca*, the yellow part), definition of.....*451*, 554
YOLK STALK 462, 484
YPSILOID CARTILAGE, ĭp'si'loid (G. *upsilon* + *eidos*, resemblance)......706

ZITTEL 388
ZOANTHARIA, zōonthā'ria (G. *zoon*, animal + *anthos*, flower).....*257*, 420
  A subclass of *Coelenterates*.
ZOANTHIDEA, zōanthĭ'dēa (G. *zoon* + *anthos*) 420
  An order of *Zoantharia*.
ZONA RADIATA, definition of.......443
ZONE OF JUNCTION, zōn (G. *zone*, a girdle), definition of 450
ZOOCHLORELLAE, zō'ôklôrĕl'ē (G. *zoon*, animal + *chloreos*, green)...286
ZOOECIUM, zōe'sium (G. *zoon*. + *oikos*, house) 310
ZOOGEOGRAPHY, zōôgēŏg'răfī (G. *zoon* + *ge*, earth + *graphein*, to write), definition of 32
ZOOLOGY, zōōl'ōgi (G. *zoon* + *logos*, a discourse) ....
  Economic 32
ZOOPHYTA, zō'ōfī'ta (G. *zoon* + *phyton*, plant), definition of.......255
ZOOSPORE, zōōspōr' (G. *zoon* + *spora*, seed), definition of......*150*, 207
ZOOTHAMNION 155
ZORAPTERA 423
  An order of *Blattaeformia*.
ZYGAPOPHYSIS, zīgăpŏf'ēsis or zĭgăpŏf'ēsis (G. *zygon*, yoke; *apophysis*, process) *682*
ZYGOMATIC, zīgōmat'ĭk or zĭgōmăt'ik (G. *zygoma*, yoke)................697
ZYGOSPORE, zī'gōspôr (G. *zygon* + *sporos*, seed), definition of.........205
ZYGOTE, zī'gōt (G. *zygotes*, yoked)..101

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